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Prototype Early Warning Fire Detection System: Test Series 3 Results

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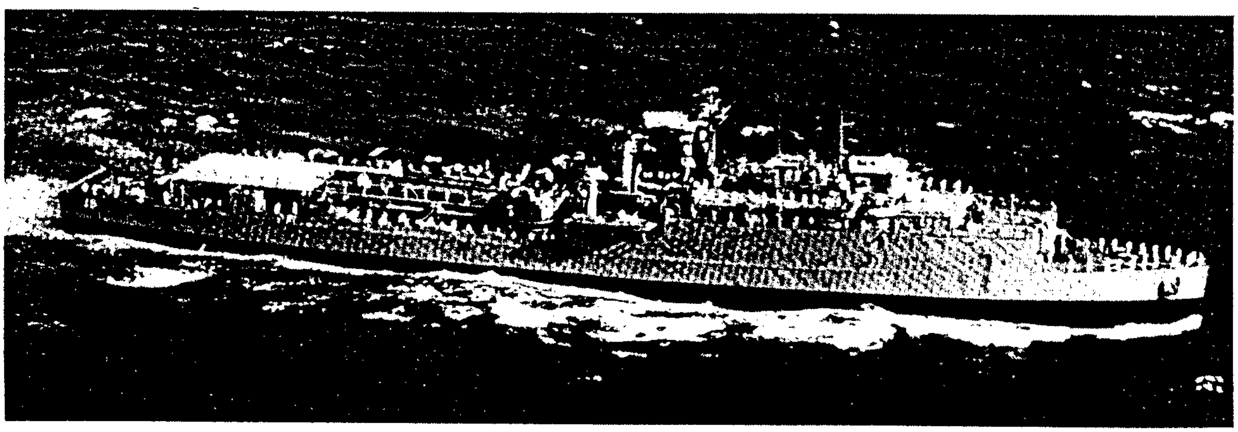

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13. ABSTRACT (*Maximum 200 words*)

This work is a continuation of a multi-year effort to develop an early-warning fire detection system (EWFD) that is immune to nuisance alarms. The work was conducted under the Office of Naval Research-sponsored program Damage Control-Automation for Reduced Manning (DC-ARM) as part of a smart system capable of providing automated damage control. Over the past two years, efforts have focused on identifying appropriate sensors and candidate multivariate alarm algorithms.

The results of this test series have demonstrated improved performance of the current probabilistic neural networks (PNN) alarm algorithm compared to previous prototype designs as well as alternate sensor/PNN combinations evaluated in this work. The current alarm algorithm resulted in better overall performance than the commercial smoke detectors by providing both improved nuisance source immunity with generally equivalent or faster response times. Areas of improvement have been identified. In particular, it is believed that the prototypes can be made to respond faster to long smoldering fires.

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PROTOTYPE EARLY WARNING FIRE DETECTION SYSTEM: TEST SERIES 3 RESULTS

1.0 INTRODUCTION

This work is a continuation of a multi-year effort to develop an early-warning fire detection system (EWFD) that is immune to nuisance alarms. The work was conducted under the Office of Naval Research sponsored program Damage Control-Automation for Reduced Manning (DC-ARM) as part of a smart system capable of providing automated damage control. Over the past two years, efforts have focused on identifying appropriate sensors and candidate multivariate alarm algorithms [1-8]. Based on this work, two prototype detection systems (two detectors of each type) were assembled and evaluated in real-time during the Series 1 tests [4] onboard the ex-USS *Shadwell*, the Naval Research Laboratory's full scale fire research facility in Mobile, Alabama [9]. Test Series 1 and 2 provided shipboard data under varying environmental conditions to be used for algorithm and prototype optimization [7,8]. Based in part on the data obtained from Test Series 1 and 2, improved alarm algorithms (i.e., probabilistic neural networks (PNN)) were developed. In addition, new prototype detectors were fabricated in preparation for the 2000 shipboard demonstration of the DC-ARM program. The full set of prototypes and the new alarm algorithms were incorporated into the 3rd test series conducted over the period of July 20 to July 28, 2000. This report documents the experimental program and results of this test series.

2.0 BACKGROUND

The system under development combines a multi-criteria (sensor array) approach with sophisticated data analysis methods. An array of sensors and a multivariate classification algorithm used together have the potential to produce an EWFD system with a low nuisance alarm rate. During an event, several sensors measuring different parameters of the environment produce a pattern vector or response fingerprint. Multivariate data analysis methods can be trained to recognize the pattern of an important event such as a fire. Multivariate classification methods, such as neural networks, rely on the comparison of events (i.e., fires) with nonevents (i.e., background and nuisance sources). Variations in the response of sensors can be used to train an algorithm to distinguish events when they occur. A key to the success of these methods is the appropriate design of sensor arrays and training sets of data used to develop the algorithm. This test series includes a variety of conditions that may be encountered in a real shipboard environment. Every effort is made to consider many representative fire situations and potential interference sources, including the use of Navy approved materials.

3.0 OBJECTIVES

The specific objectives of this test series were to:

1. Provide a broader range of signature data from real fire and nuisance sources for the purpose of further refining the current prototype detectors and classification algorithms,

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2. Evaluate the performance of the prototype detectors with the most current improvement in the classification algorithms to correctly identify real fire and nuisance sources,

3. Test and evaluate a revised method for executing real-time detection to maintain a constant sampling and processing interval of 2 seconds, and

4. Test the direct TCP/IP transfer method of transmitting data to supervisory systems via the fiber optic LAN-based Ethernet.

4.0 EXPERIMENTAL TESTING

Prototype detection systems were installed in the forward area of the ship on the second deck in the compartments between Frames 15-29. The test area is depicted in Fig. 1. The forward space from Frames 15 to 18 was designated CPO Living Space, the space from Frames 18 to 22 was designated Combat Information Center (CIC), the starboard space from Frames 22-27 was designated the Operations Office (Ops Office) and the space surrounding the Ops Office was designated the Combat Systems Office (CSO). The CSO was the primary fire compartment in this test series. The fire/nuisance sources consisted of those used during previous tests [1,2,4,5] as well as several new sources. The primary locations of the fire/nuisance sources are also shown in Fig. 1 as Location 2 and Location 3. The placement of the detectors is indicated in the figure as Location A and Location B. Video cameras and a smoke blanket were also installed in the space as shown in Fig. 1. The smoke blanket was used to isolate the alcove area of the CSO and exclude it from the test area.

4.1 Fire Scenarios

This section describes the various fire scenarios selected for testing in this program. A summary of these scenarios is provided in Table 1. All scenarios were conducted in the CSO. Fire scenarios were generally allowed to continue until all detectors in the space reported an alarm or had essentially reached a steady state.

4.1.1 Scenario F01 – Heptane Pool Fire

A small heptane pool fire was used as a typical hydrocarbon fuel used in standardized tests as well as in previous tests of this program. Approximately 260 ml (8.8 fl oz) of heptane in an 11.4 cm (4.5 in.) diameter pan were ignited with a torch, where the bottom of the pan was located 0.4 m (16 in.) above the deck. This test was conducted twice at Source Location 3. Normal test ventilation conditions for the test space were not achieved in test EWFD_089 because the Total Protection System (TPS) was disconnected from the Engineering Office due to other work occurring on the ship. Flexible tubing was used to patch the ventilation system and restore test ventilation conditions for the remainder of the test series.

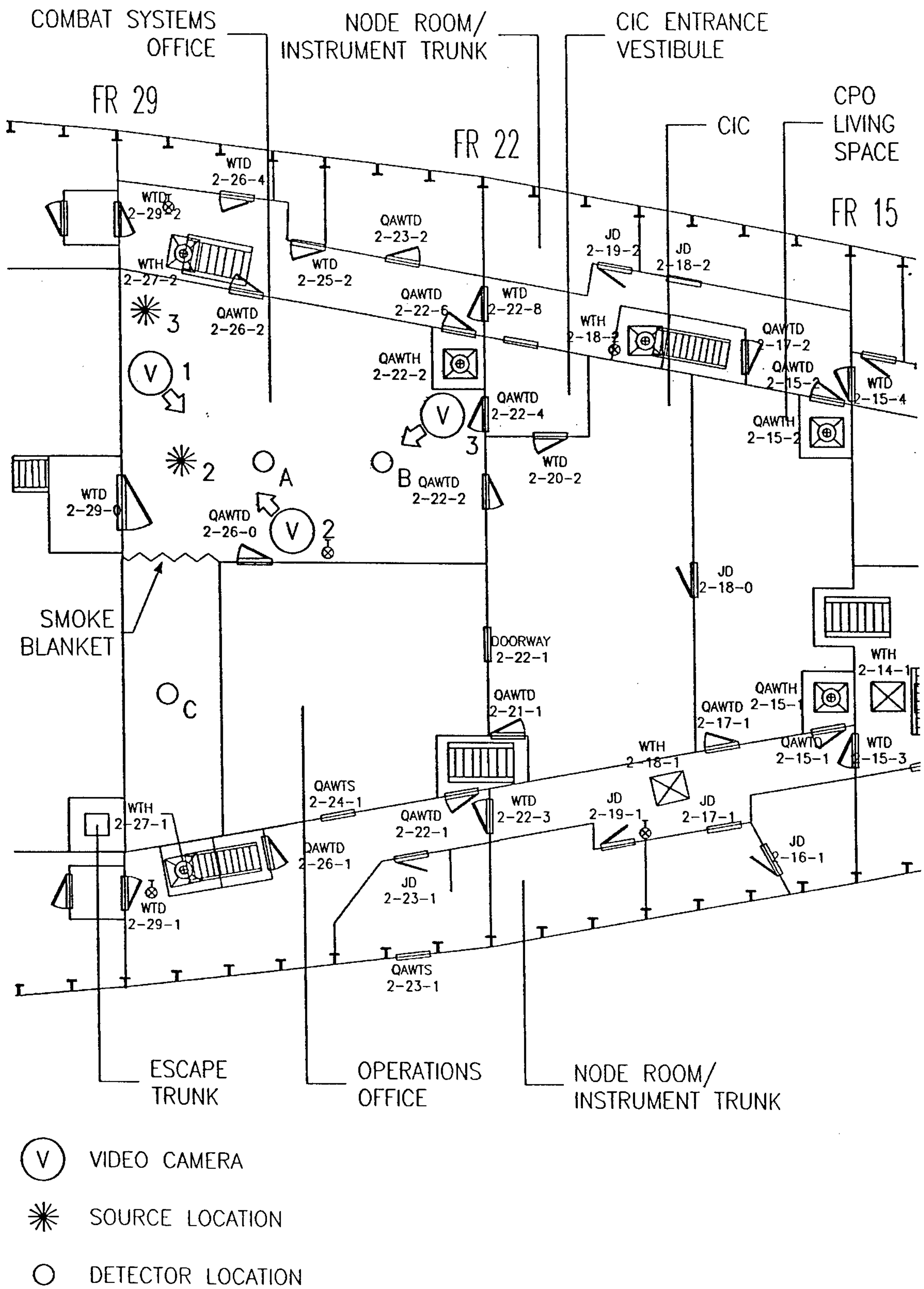

Fig. 1 – Plan view of test area on second deck.

Table 1. Summary of Fire Scenarios.

Fire Scenario	*EWFD Tests*	*Description*
F01	089,103	Heptane Pool Fire
F02	091,108	Pipe Insulation Exposed to Fuel Oil Fire
F04	125	Smoldering Oily Rag and Paper in Small Trash Can
F06	092,107	Plastic Trash Bag Fire next to TODCO Wallboard
F07	094,109	Electrical Cables and Pipe Insulation exposed to Laundry Pile Fire
F08	095,111,121	Smoldering Electrical Cables (LSDSGU-14)
F09	124	Smoldering Bedding Material
F10	098,104,116	Flaming Bedding Material
F11	099,117	Printed Wire Board Fire
F13	101,118	BSI 6266 Wire Overheat
F14	097,113,122,126	Smoldering/Flaming Electrical Cables (LSTPNW-1½ , MIL C-24643/52-01UN)
F15	100b	Burning Toast (smoldering)
F16	114b	Burning Pop-Tarts™ (smoldering)
F17	123	Smoldering Box with Packing Material

4.1.2 Scenario F02 – Pipe Insulation Exposed to a Fuel Oil Fire

Calcium silicate insulation with glass cloth lagging pipe insulation was exposed to an F-76 fuel oil fire. The insulation was obtained from Reilly Benton Insulation Co., a Navy supplier. The calcium silicate sample (MIL-I-278) was 5.1 cm (2 in.) internal pipe size and 2.54 cm (1 in.) thick. The glass lagging cloth (MIL-C-20075, Ty CL 3, Reilly Benton Type 300) was applied to the calcium silicate with MIL-A-3316 Class I Grade A adhesive (Vimasco 713).

The insulation was cut in approximately 45 cm (18 in.) long samples and mounted around PVC pipe with corresponding diameters. The lagging was then applied around the insulation per the manufacturer's instruction. After assembly, samples were painted with chlorinated Alkyd White, DOD-E-24607, Color 27880.

The insulation and pipe assembly was exposed to an F-76 flame from 11.4 cm (4.5 in.) diameter fuel pan. The fuel pan contained 260 ml (8.8 fl oz) of F-76 fuel oil with 20 ml (0.7 fl oz) of heptane accelerant. The pipe assembly was mounted horizontally, 10 cm (4 in.) above the top of the pan, and bottom of the pan was 0.4 m (16 in.) above the deck. This test was conducted twice at Source Location 3.

4.1.3 Scenario F04 – Smoldering Oily Rag and Paper in Small Trash Can

This scenario was modified from the previous test series. The two main differences were that more rags and paper were used to create a denser load and the Calrod heater was sandwiched between the rags. A 6-liter (1.6 gal) metal trashcan contained 13 full sheets of crumpled newspaper, two pieces of 0.19 m^2 (2 ft^2) cardboard, and five 0.1 m^2 (1 ft^2) cotton rags saturated with 118 ml (4 fl oz) of 10W30 motor oil. A 2.5 cm (1 in.) diameter hole was drilled into the side of the trashcan, 2.5 cm (1 in.) above its bottom. A 14.7 cm (5.5 in.) Calrod [Ogden Model MWEJ05J1870, 700Watt, 125Volt] was inserted into the hole of the trashcan. About 90% of the length of the Calrod was inserted through the hole. The arrangement of materials in the trashcan was as follows (from bottom to top): rags, Calrod, rags, and paper. The cardboard was folded and situated so that it was upright in the can around the sides. In order to cause smoldering, the Calrod was energized via a variac to 40% of capacity. The bottom of the trashcan was 0.4 m (16 in.) above the deck. This test was conducted once at Source Location 3.

4.1.4 Scenario F06 – Flaming Plastic Bag of Mixed Trash Next to TODCO Wallboard

A plastic trash bag containing various typical waste items, such as paper towels, newspaper, cans, food containers, fruit, and banana peels was placed next to the vertically supported wallboard. The trash bags were actual trash bags and contents obtained from the crew's mess deck onboard the ship. The dimensions of the bag were 2 m (6.5 ft) in circumference and 0.9 m (3 ft) deep (approximately a 55 gallon bag). The trash bag was placed in a pan and ignited at its base with a butane lighter at a spot between the bag and the pan wall. The base of the trash bag was 0.4 m (16 in.) above the deck. This scenario was conducted twice at Source Location 3.

The white, TODCO Engineering Products, Nomex panel used in this test was a non-filled honeycomb with phenolic resin impregnated fiberglass facing over the aramid fiber honeycomb core. The dimensions of the sheet used were 0.6 m x 0.6 m (2 ft x 2 ft) and the honeycomb was 0.6 cm (0.25 in.) hexagonal MIL SPEC MIL-C-81986, with a density of 48 kg/m^3 (3 lb/ft^3). The overall panel thickness was 1.6 cm (+0.000 cm, - 0.08 cm) (0.625 in. (+0.000 in., -0.030 in.)) thick including the decorative face sheets. The decorative face sheets were high-pressure plastic laminate (HPPL) in accordance with MIL SPEC MIL-P-17171, Type IV except that they were 0.07 cm - 0.09 cm (0.027 in. - 0.037 in.) thick. The HPPL was bonded directly to the fiberglass face sheet using the phenolic resin system per MIL SPEC MIL-R-9299, Grade A.

4.1.5 Scenario F07 – Electrical Cables and Pipe Insulation Exposed to a Laundry Pile Fire

Electrical cables and pipe insulation (as described in Section 4.1.2) were exposed to a laundry pile fire. Four 1 m (39 in.) lengths of LSDSGU-14 cable were vertically supported next to a 0.5 m (19.5 in.) vertical section of insulated pipe. The 9AWG, 3-conductor cable was manufactured by Monroe Cable Co, Military Part No. M24643/16-04UN. The cable consisted of cross-linked polyolefin jacket with silicon rubber insulation on the conductors. The fire was initiated at the base of the laundry pile, between cable/pipe insulation and the pile using a butane lighter. The base of the laundry pile, pipe with insulation, and cables were 0.4 m (16 in.) above the deck. This test was conducted twice at Source Location 3. For the first test (EWFD_094), the laundry pile consisted of 2 medium Hanes® undershirts (100% cotton), 1 medium Fruit of the Loom® brief (90% cotton, 10% polyester), 1 long sleeve shirt (100% cotton), 1 Polo® shirt (50% cotton, 50% polyester), and 1 size 42 dress (100% cotton.). The second test (EWFD_109) laundry pile consisted of 1 medium Hanes® T-shirt (100% cotton), 1 medium Fruit of the Loom® brief (100% cotton), 1 size 20 denim dress (100% cotton), 1 medium shirt (50% cotton, 50% acrylic), 1 large sweater (100% acrylic), and 1 size 16 dress (100% rayon).

4.1.6 Scenario F08 – Smoldering Electrical Cables (LSDSGU-14 and LSTSGU-9)

This test simulated a long smolder of the LSDSGU-14 cable described in Section 4.1.5, and the LSTSGU-9 cable (both with a length of 33 cm [13 in.]). The LSTSGU-9 cable was a 3 conductor, 10 AWG cable manufactured by Monroe Cable Co, Military Part No. M24643/16-03UN. The cable consisted of cross-linked polyolefin jacket with silicon rubber insulation on the conductors. (The LSTSGU-9 cable is actually the one that was used in Test Series 2 tests). The jacket and insulation were stripped back on both ends exposing 1.25 cm (0.5 in.) of the conductors. The arc welder was clamped to one or more conductors on one end of the cable and the other end was grounded to a metal stand via a clamp. The bottom of the vertically supported cable was approximately 30 cm (12 in.) above the deck. After initial background data were collected, the arc welder was energized to 375 A. The cables remained energized until the end of the test or until they stopped smoking. The result was the slow heating of the cable that produced light smoke until the insulation broke, causing an increase in smoke production. The amount of smoke production cycled with the power of the arc welder, as increasing smoke was noted with the sound of the welder ramping up its power, and decreasing smoke was noted as the sound of the welder indicated that it was ramping down in power.

This test was conducted twice at Source Location 3. During the first test (EWFD_095), only one LSTSGU-14 cable was used. Initially, two of the conductors were energized at 100% (375A) until the cable stopped smoking. The leads from the welder were then de-energized, removed, re-attached to the last conductor, and re-energized for the remainder of the test (starting 1465 seconds after initiation). For the second test (EWFD_111), one LSTSGU-9 cable was used with two conductors initially energized at 100% (375A). During this test insulation (Fiberfrax)) was wrapped around the cable at approximately 2730 seconds after initiation. Smoke production was minimal at this time, and the insulation was added in an attempt to increase the smoke production by causing the cable to retain more heat. The two conductors fused (stopping smoke production) and the welder leads were switched to the last conductor 3947 seconds after initiation. The last test (EWFD_121) used two LSTSGU-9 cables over the course of the test. Only one conductor of the cable was energized at a time, until it stopped smoking. In general, the cable smoked for about 15 to 40 seconds, after which the jacket split. A burst of smoke was released at the time of the split, and light smoking continued for another 25 to 80 seconds. The leads were then de-energized, removed, re-attached to another conductor, and re-energized at a lower current setting. The conductors of the first cable were tested with the 375A welder at levels of 100% (602 seconds in duration, conductor 1), 75% (124 seconds in duration, conductor 2), and 50% (70 seconds in duration, conductor 3). A second cable was tested in the same way, using welder levels of 40% (109 seconds in duration, conductor 1), 30% (58 seconds in duration, conductor 2), and 20% (177 seconds in duration, conductor 3). The percentages correspond to an operating range of 375A (100%) to 75A (20%). These tests likely varied from those in previous test series due to new, smaller gauge welding cables (replacement cables for the old equipment) which were believed to have affected the heating of the test sample. The old welding cables were no longer available.

4.1.7 Scenario F09 – Smoldering Bedding Materials

A Navy mattress (MIL-M-18351F(SH)) consisting of a 11.4 cm (4.5 in.) thick Safeguard polychloroprene foam core covered with fire retardant cotton ticking was outfitted with the following items:

1. Two sheets – Federal Specification DDD-S-281,
2. One blanket – Federal Specification DDD-S-281,
3. One bed spread- Federal Specification DD-B-151.
4. One mock-up pillow – A Navy feather pillow (Federal Specification V-P-356, Type 4) and a pillowcase (Federal Specification DDD-P-351) were cut and stapled into a 0.2 m x 0.2m (2 ft x 2 ft) sample.

This test was conducted once at Source Location 3. The bedding sample was layered in the following order (from the bottom up): mattress, loosely piled bedding (sheets, blanket, and bed spread), and the pillow. The smoldering fire source consisted of placing one square sample 0.4 m (16 in.) above the deck, with a 700 W Calrod placed between the mattress and the loosely piled bedding. Approximately 1 in. of the Calrod was exposed to air. The Calrod was energized with a variac to 40% of capacity, and was allowed to rest on the sample under its own weight, remaining energized for the duration of the test. The Calrod was increased in power to 60% of capacity 86 minutes after initiation, and then to 80% at 91 minutes after initiation.

4.1.8 Scenario F10 – Flaming Bedding Material

The same bedding sample components described in Section 4.1.7 were used in this test. One sheet of crumpled newspaper placed on top of the mattress, next to the pillow was used as the initiating source for this fire. The bottom of the sample was 0.4 m (16 in.) above the deck. A butane lighter was used to ignite the newspaper. The burning newspaper caused the pillow to smolder, which subsequently caused flaming combustion of the feathers in the pillow. This test was conducted three times at Source Location 3. The first test (EWFD_098) was conducted as just described. The second and third tests were intended to be smoldering bedding material as described in Section 4.1.7; however, they transitioned to flaming fires rather quickly after the initiation of the Calrod. For the second test (EWFD_104), the Calrod was placed between the mattress and the loosely piled bedding and energized to 75%. Flaming ignition occurred 158 seconds later. The third test (EWFD_116) was the same as the second, except that the Calrod was energized to 60%. Flaming ignition occurred 335 seconds after the Calrod was energized.

4.1.9 Scenario F11 – Printed Wire Board Fire

Internal Printed Wire Board (PWB) failures are also a fairly common event in electronic equipment. These are generally caused by contaminates within the PWB, a by-product of the manufacturing process, but can also be induced by component failures and/or power surges. In reference [10], the PWB test was specially designed to replicate fires in circuit boards. The test board was fabricated with two parallel 50 mil wide tracks, spaced 50 mil apart. The tracks extended to one end of the 41-cm long board where solder coated pads were provided to connect the circuit to the power supply. At the opposite end of the 38 cm long tracks, a 10 mil wide track bridged the long tracks to complete the circuit and provide a short length of higher resistance track where localized heating could develop and in time lead to the formation of an arc. The test board was fabricated of FR-4 substrate material, and the board was coated with dry film solder mask, materials typical of those used in telecommunications equipment manufacture.

The overheated power tracks, aligned parallel to one another, pyrolyze or carbonize the substrate material between them. After a time, the insulating properties of the material are sufficiently degraded that an arc develops between the two tracks, igniting the gaseous pyrolysis products. A flame about ½ inch tall results, and travels along the tracks with the progressing arc. The process is self-sustaining as long as power is applied to the circuit. The arc travels along the tracks starting at the point of ignition and moves closer to the connecting pads at the end of the PWB.

The test PWB was mounted vertically in a stand (1.2 m (4 ft) above the deck) with the tracks aligned parallel to the deck, and connected to the leads of a Kenwood model PD18-3AD regulated DC power supply. The tests were conducted with the regulated DC power supply set to deliver a constant current of 8.5 A with a peak voltage setting of 6.0 V. The test PWB was mounted between two non-energized PWB. This test was conducted twice at Source Location 2. For the first test (EWFD_099), two boards were tested in sequence due to a failure in the first board to sustain an arc. During the second test (EWFD_117), a second board was also used after the first PWB failed to heat and smoke properly. A portable fan was set up to blow along the second PWB approximately 15 minutes after it was energized. The fan was used to increase smoke movement in the overhead since few detectors were reaching alarm.

Note that consistency in board manufacturing, and possibly the contact between the power leads and the PWB circuit, appeared to affect the preheat time of the boards. This is directly evidenced by the inability of the first board in each of the tests to sustain an arc. The time needed to heat up the boards from initiating the power source to arcing of the circuit varied from test to test. The time recorded between initial energizing and the first appearance of an arc was 424 seconds and 252 seconds for tests EWFD_099 and EWFD_117, respectively. These times are for the second board used in each test.

4.1.10 Scenario F13 – BSI 6266 Wire Overheat

British Standards Institute standard BS 6266, *"Code of Practice for Fire Protection for Electronic Data Processing Installations"* [11] details five test methods for testing smoke detection systems in electronic data processing facilities. These tests are intended to replicate the types and/or quantities of smoke produced in the early stages of a fire in a telecommunications or data processing facility. One of these tests is intended to represent a potential electrical fire via ohmically heating a sample of wire. The wire used is specified by the standard to be constructed of ten, 0.1 mm strands, insulated with PVC to a radial thickness of 0.3 mm, with a cross-sectional area of 0.078 mm^2. The wire was obtained from Vision Systems, UK.

This test was conducted twice at Source Location 2. In each test, a 1 m long wire (BSI 6266 spec) was heated at 6 V (28 A) for 60 seconds using the Kenwood power supply described in Section 4.1.9. After the first wire was removed, a second was installed, energized, and allowed to completely burn. The BSI 6266 wire was wrapped around an inert strip of marinite board that was supported approximately 1.5 m (5 ft) above the deck.

4.1.11 Scenario F14 – Smoldering/Flaming Electrical Cables (LSTPNW-1½)

This source was intended to represent an early stage electrical fire. The setup consisted of energizing several cables of a larger bundle to induce a smoldering Class C initiated fire. The wire used (Monroe Cable Co., LSTPNW-1 ½, MIL C-24643/52-01UN) was a 22 AWG, 3-conductor cable with a cross-linked polyolefin jacket and cross-linked polyethylene insulation. Ten 33 cm (1.1 ft) cables were bundled together in these tests. The jacket and insulation were stripped back on both ends exposing 1.25 cm (0.5 in.) of the conductors. The arc welder was clamped to the conductors on one end of the cable and the other end of the cables was grounded to a metal stand via a clamp. The bottom of the vertically supported cable was approximately 5.7 cm (2.3 in.) above the deck. The cables remained energized for the entire test period. The result was the slow heating of the cable that produced light smoke until the insulation broke, causing the smoke to become heavier. This test was conducted four times at Source Location 3. In the first test (EWFD_097), the welder was set to 375 A and 15 conductors were connected to the arc welder. This test was classified as a "flaming" fire source because the transition to flaming occurred quickly after the conductors were energized (159 seconds). The second test (EWFD_113) was setup the same as the first test, except that 13 full sheets of crumpled newspaper were placed on the deck around the bundle of cables. The paper was intended to be a secondary fuel to be ignited by the cable which would flame for less than a minute. This test was also classified as a flaming fire source, as flaming ignition of the cable occurred 169 seconds after the conductors were energized. The paper did not ignite. The third test (EWFD_122) used the same setup as the second test, except that only 7 full sheets of crumpled newspaper were placed on the deck next to the bundle, and the welder was set to 50% power. The onset of flaming ignition in this test was delayed to 388 seconds after the conductors were energized; therefore, this test was classified as a smoldering fire source up until the time of ignition. The last test (EWFD_126) was conducted differently from the first three in order to achieve a longer smoldering fire that produced visible amounts of smoke. In this test, 30 of the cables were bundled together, and a Calrod was inserted into the middle of the bundle. There were approximately 2 layers of cables around the Calrod. The Calrod was initially set to 40% of capacity using a variac, and was increased in steps to 100% during the test. The steps were as follows (times are in reference to the initial initiation of the Calrod): 50% at 440 seconds, 60% at 838 seconds, 70% at 2017 seconds, and 100% at 2718 seconds. This test was classified as a smoldering fire source.

4.1.12 Scenario F15 – Burning Toast

This test was simply an extension of the "Normal Toasting" nuisance source (see Section 4.2.6), representing the time beyond which the toasting cycle had transitioned from a nuisance source to a smoldering fire source. The last eight slices of bread toasted in test EWFD_100a were allowed to burn by toasting continuously. The key to this test was defining the time at which the transition from a nuisance event to a fire occurred. For this test, the transition was defined as the time when the toast became visibly black around the edges (not generally considered edible) and smoke was visibly emanating from the toaster. This occurred approximately 665 seconds after the *first* set of bread was put into the toaster in test EWFD_100a. For reference, the burnt toast was toasted approximately 228 seconds before the transition occurred. This test was conducted once at Source Location 2.

4.1.13 Scenario F16 – Burning Pop-Tarts™

Similar to the "Burning Toast" scenario (Section 4.1.12), this test was simply an extension of the "Toasting Pop-Tarts™" nuisance source (see Section 4.2.1), representing the time beyond which the toasting cycle had transitioned from a nuisance source to a smoldering fire source. The last eight Pop-Tarts™ toasted in test EWFD_114a were forced to burn by toasting continuously. The key to this test was defining the time at which the transition from nuisance to fire occurred. For this test, the transition was defined as the time when the Pop-Tarts™ became visibly black around the edges (not generally edible) and smoke was visibly emanating from the toaster. This occurred approximately 772 seconds after the *first* set of Pop-Tarts™ was put into the toaster in test EWFD_114a. For reference, the burnt Pop-Tarts™ were toasted approximately 223 seconds before the transition occurred. This test was conducted once at Source Location 2.

4.1.14 Scenario F17 – Smoldering Box with Packing Material

This test was intended to emulate a fire in a storage area on a ship, involving packaging materials. A corrugated cardboard box (0.48 m x 0.61 m x 0.36 m high [19 in. x 24 in. x 14 in. high]) was filled with blown-in rigid polyurethane packing material and polyethylene sheeting and placed on top of a stand so that its bottom was approximately 0.4 m (16 in.) off the deck. A small hole for a Calrod was placed in the center of the long side of the box, approximately 0.13 m (5 in.) from the bottom. A Calrod was placed in the hole and energized to 40% of capacity using a variac. During the test, the Calrod energy was changed several times as follows (times represent seconds after the initial initiation of the Calrod): 80% at 1179 seconds, 60% at 1379 seconds, and back to 80% at 1994 seconds. Flaming ignition occurred 2123 seconds after the first initiation of the Calrod, and the test was terminated shortly thereafter. This test was conducted once at Source Location 3.

4.2 Nuisance Scenarios

This section describes the various nuisance scenarios selected for testing in this program. A summary of these scenarios is provided in Table 2. All of these scenarios were conducted in the CSO. Most sources were located at Source Location 2. A number of the sources did not cause smoke detectors to reach alarm levels despite moving the sources closer and exceeding extreme exposures.

Table 2. Summary of Nuisance Scenarios.

Nuisance Scenario	*EWFD Tests*	*Description*
N01	093,114a	Toasting Pop-Tarts™
N02	096,120	Welding Steel
N03	105,115	Cutting Steel with acetylene torch
N04	102,112	Burning popcorn
N05	106	Cigarette smoke
N06	100a	Normal Toasting
N07	110,119	Grinding Steel

4.2.1 Scenario N01 – Toasting Pop-Tarts™

In these tests, two four-slice toasters (Toastmaster Model D165, 120 V, 50-60 Hz, 1700W) were filled with chocolate frosted Pop-Tarts™ and set to "dark". In the first test (EWFD_093), the first set of Pop-Tarts™ was toasted for 272 seconds, and then eight new ones were immediately started (toasted for 266 seconds). In the second test (EWFD_114a), the first eight Pop-Tarts™ were toasted for 246 seconds and a second set was started immediately after the first (toasted for 233 seconds). The third set of Pop-Tarts™ was purposely burnt in the toasters. This portion of the test was re-classified as a fire source and is described in Section 4.1.13 as test EWFD_114b. The bottom of the toasters was 1.2 m (4 ft) above the deck in both tests. This source was used to produce a different type of cooking effluent than previously obtained with toast. These tests were conducted at Source Location 2.

4.2.2 Scenario N02 –Welding Steel

Welding and other hot work are typical maintenance activities that can occur onboard a ship. Welding of steel was conducted in the compartment 0.4 m (16 in.) above the deck. The arc welding consisted of running a weld across a 0.6 cm (0.25 in.) thick steel plate using a 0.32 cm (0.125 in.) number 7018 rod and a constant current setting of 100 A. A total of 7 rods were used during the 10.5-minute exposure time in the first test (EWFD_096), and 10 rods were used during the 11-minute exposure of the second test (EWFD_120). Both tests were conducted at Source Location 2.

4.2.3 Scenario N03 – Steel Cutting

An oxy-acetylene torch with a #1 Victor tip was used to cut a 0.32 cm (0.125 in.) thick steel plate, 0.4 m (16 in.) above the deck. Cutting occurred in a continuous fashion by cutting off 5 cm (2 in.) wide strips of steel from the plate. The cut strips varied in length, as the plate was not a regular rectangle. Cutting was essentially continuous for about 3 minutes in the first (EWFD_105) and second (EWFD_115) tests. Both tests were conducted at Source Location 2.

4.2.4 Scenario N04 – Burning Popcorn

A typical bag of microwave popcorn (ACT II, Butter Lovers, 3.5 oz bag) was cooked on high in an 850 W microwave oven (a Tappan Model TMT1046150) for 12 minutes. The bottom of the microwave was 1.2 m (4 ft) above the deck. In both tests, the popcorn was a black mass of char by the end of the 12-minute period. In the first test (EWFD_102), the popcorn bag was opened approximately 30 seconds after the 12-minute period had ended. The smoke released after this time was not considered as part of the test, since the bag was directly below the Location A detectors and was not uniformly distributed across all the detectors at that location. Visibly, the source produced the same if not more smoke than the toast scenario. Therefore, as with many nuisance sources, a subjective determination must be made whether the source remains a nuisance or a precursor to a fire at the later stages of the test when a plume of smoke is issuing from the microwave. Since the source is contained within the microwave and ignition was not observed, the scenario has been considered a nuisance source throughout the entire time of the test. This classification may need to be reconsidered depending on the role of the EWFD system with respect to the entire casualty response system. This test was conducted at Source Location 2.

4.2.5 Scenario N05 – Cigarette Smoke

Although smoking is prohibited inside Navy ships, it still remains a very plausible nuisance source. This test consisted of four people smoking cigarettes/cigars in the test compartment, where each person smoked 3 to 4 cigarettes (Camels™, Salems™, Salem Menthols™ and Black 'n' Mild™ cigars). In this test, four people smoked a total of 11 cigarettes and two cigars in 17 minutes. The smokers were standing and walking around the compartment during the test. Note that during the ventilation portion of this test, some running machinery and hot work were present in the well deck. It is likely that gases from these operations were drawn into the test compartment during the ventilation period.

4.2.6 Scenario N06 – Normal Toasting

In this test, two four-slice toasters (Toastmaster™ Model D165, 120 V, 50-60 Hz, 1700 W) were filled with white bread and set to "dark". Eight slices of bread were toasted at a time resulting in very dark toast. The first set of bread was toasted for 211 seconds, and the second set was toasted for 180 seconds. The third set of bread was purposely burned in the toaster, as described in Section 4.1.12. The bottom of the toasters was 1.2 m (4 ft) above the deck at Source Location 2.

4.2.7 Scenario N07 – Grinding Steel

A handheld grinder was used to grind a rusty steel plate in these tests. The grinder used was a Black and Decker™ 4.5 in. Angle Grinder, Model 2750G, with an 11 cm (4.5 in.) diameter, 0.6 cm (0.25 in.) thick Norton™ General-Purpose Mini Disc grinding pad. The grinding took place approximately 0.4 m (16 in.) above the deck in the first test (EWFD_110) and 1.2 m (4 ft) above the deck in the second test (EWFD_119). Grinding was conducted at Source Location 2 for 10.5 minutes in the first test and 8.5 minutes in the second test.

4.3 Sensor Calibration Tests

Sensor calibrations/tests were performed at Hughes Associates, Inc., Baltimore, MD before the beginning of this test series for the relative humidity (Omega HX93V and HX93C), carbon monoxide (City Technology TB7F-1A), and carbon dioxide (Telaire/Engelhard 2001V and 8002W) sensors on the prototypes. The relative humidity and carbon monoxide sensors were calibrated via manufacturers' instructions. The relative humidity sensor was calibrated with salt solutions, which provided reference points of 11 and 75% (Omega HX92-CAL kit). The carbon dioxide sensors were checked by exposing the units to CO_2 gas in nitrogen, as well as 100% nitrogen. Table 3 shows the results of the relative humidity sensors performance before and after they were calibrated compared to an Omega relative humidity sensor (model RH71 with an accuracy of $\pm$2 % RH). Table 4 shows the results of the carbon monoxide sensor calibrations and Table 5 shows the results of the check of the carbon dioxide sensors. The gas used for these operations was 2000 ppm CO_2, 45 ppm CO, with the balance N_2. As can be seen from these Tables, the only sensor that was outside the accuracy limits was the 2001V on EWFD prototype 1, which was +40 ppm outside of reported tolerances.

Table 3. Relative Humidity Sensor Calibration Results

EWFD #	Model #	Serial #	Before Calibration: Hand Held % RH	Before Calibration: HX93 % RH	After Calibration: Hand Held % RH	After Calibration: HX93 % RH
1	HX93C	EA154	39.9	42.8	70	69
2	HX93C	EA086	NA	4 to 6	42.2	43.6
3	HX93C	AA142	50.9	30	52.8	51
4	HX93C	L9129	61.1	46	57.5	55.5
5	HX93C	EA120	37	31	41.1	40
6	HX93C	DA179	54.4	40.1	52.4	51.7
7 (spare)	HX93C	EA086	66.5	67	66	67

Reported Accuracy = ±2% RH

Table 4. Carbon Monoxide Sensor Calibration Results (45ppm CO gas)

EWFD #	Model #	Serial #	Before Calibration: low end ppm	Before Calibration: with 45 ppm gas ppm	After Calibration: Low end Ppm	After Calibration: with 45 ppm gas ppm
1	CO	675089	-0.5+/- 0.5	43	0+/-1	45+/- 1
2	CO	659653	-1	39	0+/-0.2	45+/- 1
3	CO	574310	0 +/- 1	38	+/- 0	45+/- 0.5
4	CO	659652	0 +/- 1	46+/- 1	0 +/- 1	45+/- 1
5	CO	675093	0 +/- 1	39	0 +/- 1	45+/- 1
6	CO	675087	0 +/- 1	38	0 +/- 1	45+/- 1

Reported Accuracy = ±2% of maximum reading (2ppm for 100ppm sensor)

Table 5. Carbon Dioxide Sensor Check Results (2000ppm CO_2 gas)

EWFD #	Model #	Sensor Reading (ppm)
1	2001V	2140
2	2001V	1920
3	8002W	2023
4	8002W	2099
5	8002W	2005
6	8002W	2063

Reported Accuracy = greater of ±5% of reading or ±100ppm

5.0 EXPERIMENTAL SETUP

5.1 Test Area and Closures

The test area for this series was FR 15 to 29 on the second deck (Figs. 1 and 2). This test area consisted of four spaces. The forward space from FR15 to 18 was designated CPO Living Space, the space from FR18 to 22 was designated CIC, the starboard space from FR22 to 27 was designated as the Operations Office (Ops Office), and the surrounding space to the Ops Office was designated the Combat Systems Office (CSO). All fire/nuisance sources were located in the CSO. Two source locations were used in this test series, as indicated in Fig. 1. A fire curtain was installed over the entrance to the starboard alcove of CSO to prevent further smoke migration to this area (indicated in Figs. 1 and 2).

Two major ducts were present in CSO at the time of testing and are shown in Fig. 2. Both ducts were approximately 0.46 m (18 in.) in width and 0.53 m (21 in.) below the overhead. Each duct was 0.48 m (19 in.) deep, although duct #2 had some variation. The aft portion of duct #2 was only 0.23 m (9 in.) wide. The ducts had a noticeable effect on the flow of the low momentum smoke from the sources, particularly those at Location 3. The ducts generally appeared to block and impede the flow of smoke. In some cases, smoke appeared to flow below the ducts before passing over the ducts along the overhead.

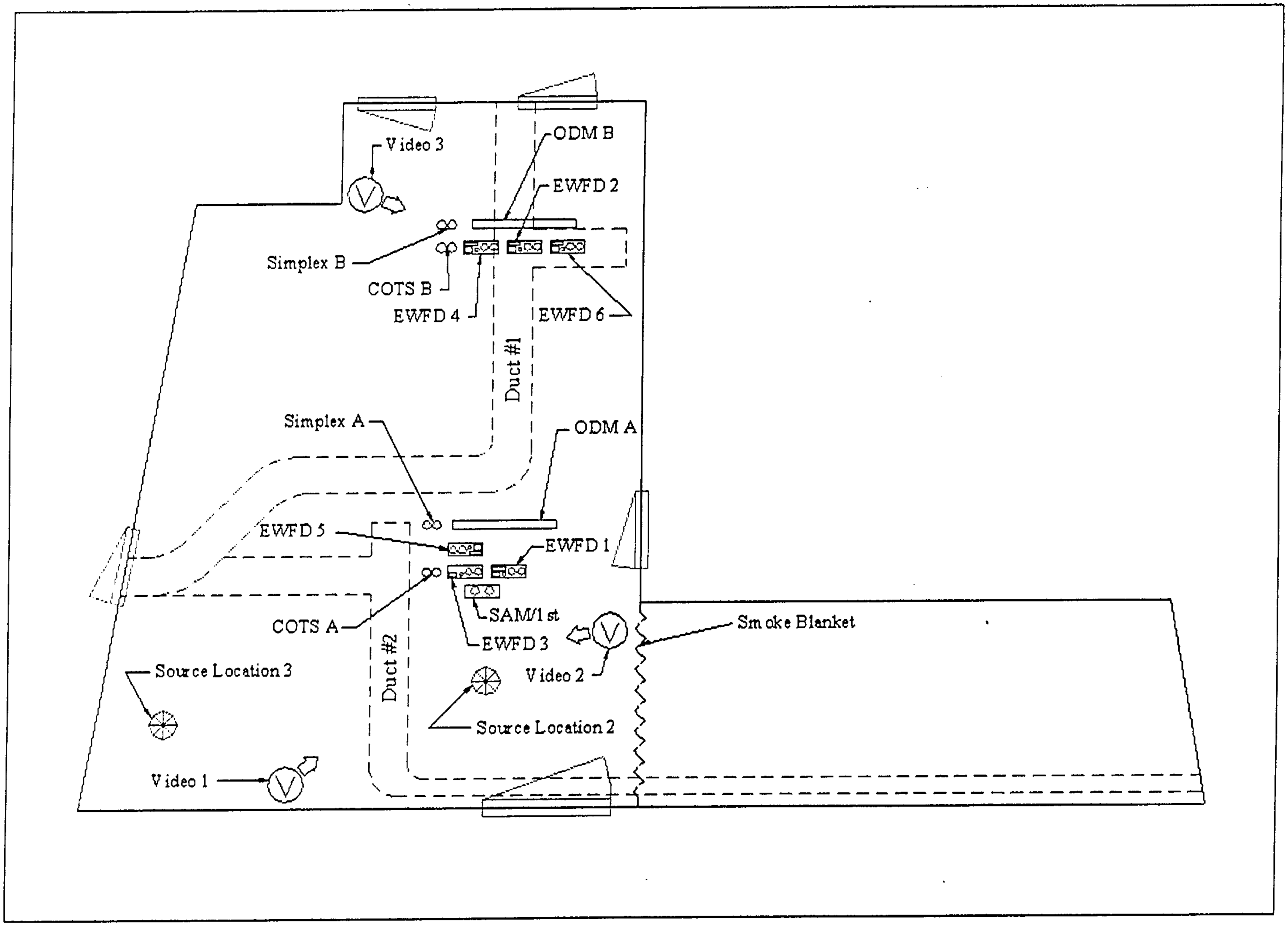

Fig. 2 – Locations in the combat systems office.

All perimeter doors and scuttles were closed to the test area during each test. The following closure plan was used to allow ventilation between compartments in the test area:

Fittings that were open:

1.	QAWTD	2-17-1
2.	JD	2-18-0
3.	Doorway	2-22-1
4.	QAWTD	2-22-4
5.	QAWTD	2-26-0

Fittings that were closed:

1.	QAWTH	2-15-1
2.	QAWTH	2-15-2
3.	WTD	2-29-0
4.	QAWTD	2-21-1
5.	QAWTD	2-22-2
6.	QAWTS	2-24-1
7.	QAWTD	2-26-2

The ventilation in the space consisted of the Total Protection Exhaust System (TPES) drawing air through one exhaust duct positioned within the Engineering Office, which is located between FR20 and FR22 on the port side of CIC. The ventilation through the TPES ducts was different from previous test series due to construction work being conducted on the ship during this test series. The construction resulted in temporary modifications of the ductwork during the series and the use of only one exhaust port. Supply air was provided through the open fittings in the test area. The general flow pattern was from the starboard passageway through CPO, CIC, Ops Office, and across the CSO test space. The measured airflow rate at the opening of the TPES duct was 322 cfm. This airflow rate effectively produced 3.8 air changes per hour in the CSO, which has an open volume of approximately 144 m^3 (5100 ft^3). This ventilation is close to the 4 to 5 air changes per hour that is typically found on Navy ships [12].

5.2 Prototype Fire Detection System

One prototype fire detection system configuration was evaluated in this test series. The detection system consisted of a group of sensors, a data acquisition system and a desktop computer used to implement the alarm algorithm processing, data storage, and display. The details of the prototype detectors and the data acquisition system are discussed in the following sections.

5.2.1 Sensors

All six prototype detectors consisted of the same group of sensors and probabilistic neural network (PNN) alarm algorithm. The PNN used in this test series was an updated version from that used in Test Series 1 and 2, reflecting the new sensor combination and general improvements [4,5]. Table 6 shows the sensor details for each of the prototypes. Six sensors were physically available on the prototypes for monitoring; however, only four sensors (ion, photo, CO and CO_2) were used in the real-time alarm algorithm for classifying events. The extra sensors were used to evaluate alternative combinations during post-test data processing after each test. The sensors of a detector were mounted together as a single assembly, as shown in Fig. 3. The sensors were mounted on a steel chassis that encased a power supply and much of the wiring. The chassis was also designed with mounting flanges to fasten it to the overhead and hinges on one side to allow interior access while the prototypes were mounted to the overhead. Six System Sensor ionization and six photoelectric detectors were used for the six prototypes. Empirical correlations (based on UL 268 smoke box data) were used to convert the sensor outputs to engineering units. The conversions used are listed in Table 7. The ionization ΔMIC (picoamperes) value was converted to percent obscuration per meter using a second empirical correlation developed from UL 268 smoke box test data comparing the System Sensor output to that of the smoke detectors used in the laboratory testing and Shadwell testing in FY 1998 [1] and FY 1999 [2]. The correlation is as follows: $\%/ft = 0.0465(\Delta MIC) - 0.6572$.

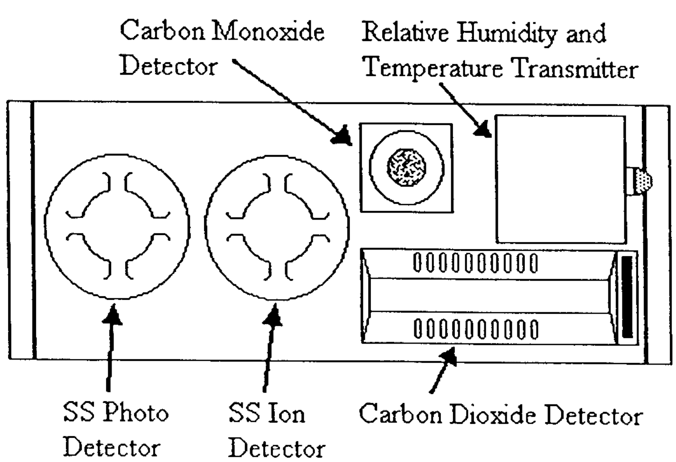

Fig. 3 – Physical layout of sensors when mounted on chassis.

Table 6. Details of Prototype Fire Detectors.

No.	*Species*	*Sensor Range*	*Resolution*	*Instrument Model No.*	*Manufacturer*
1	Ionization smoke detector	ΔMIC ~ 40		1251 with base no. B501	System Sensor
2	Photoelectric smoke detector	0.052-12.5 %/m (0.016 - 4 %/ft)	0.052 %/m (0.016 %/ft)	2251 with base no. B501	System Sensor
3	Carbon monoxide ($CO_{100\ ppm}$)	0-100 ppm	0.5 ppm	TB7F-1A	City Technology
4	Relative humidity (RH)	0-100%	$\pm$2% RH accuracy	HX93C	Omega
5	Temperature (Temp Omega)	-20C to 75C	$\pm$0.6EC accuracy	HX93C transmitter (RTD)	Omega
6	Carbon dioxide (CO_2)	0-5000 ppm	Accuracy= greater of $\pm$5% of reading or $\pm$100 ppm	2001V (EWFD1 and 2 only), 8002W Ventostat	Telaire/Engelhard

Table 7. Conversions of System Sensor Detectors Used in the Prototypes

Detector Type	*Prototype*	*Conversion*
Ionization 7	1	ΔMIC = ΔV * 50
Photoelectric 1	1	%/ft = ΔV * 2.7
Ionization 2	2	ΔMIC = ΔV * 50
Photoelectric 2	2	%/ft = ΔV * 2.5
Ionization 5	3	ΔMIC = ΔV * 50
Photoelectric 4	3	%/ft = ΔV * 2.4
Ionization 3	4	ΔMIC = ΔV * 50
Photoelectric 3	4	%/ft = ΔV * 3.0
Ionization 11	5	ΔMIC = ΔV * 48
Photoelectric 9	5	%/ft = ΔV * 3.5
Ionization 12	6	ΔMIC = ΔV * 48
Photoelectric 10	6	%/ft = ΔV * 4.0

5.2.2 Data Acquisition and Processing

Each sensor was hard-wired to the data acquisition system, which was located in the starboard side Node Room (see Fig. 1). The data acquisition system consisted of National Instruments hardware (SCXI 1001 Chassis, SCXI 1100 modules, and SCXI 1303 Terminal Blocks) controlled via LabVIEW 5.1 full development software. The data acquisition system was operated using a Dual Pentium 200 MHz PC computer running Windows NT (128 MB RAM). The LabVIEW software was used to develop a data acquisition controller that could acquire data and execute the PNN alarm algorithm in real time, save the data, display the data, and send the data to a computer in the Control Room via the fiber optic Ethernet [13]. This software was also updated for this test series to include the ability to transfer data to supervisory control groups via TCP/IP. Additionally, logic switches were added to the program in order to put flags in the output file, which marked the occurrence of different events. The PNN software (originally written with MATLAB) was rewritten for this test series using a linear algebra function library compiled into a Windows Dynamic Link Library (DLL) file that could interface with LabVIEW. During tests, the data acquisition/processing system was synchronized in time with the COTS Simplex smoke detection system currently installed on the ship. A more detailed explanation of the data acquisition system can be found in Appendix A, and an explanation of the format of the data available to the supervisory control groups is provided in Appendix B.

5.2.3 Detector Locations

The prototype detectors were co-located with the ship's COTS detection system (Simplex photoelectric and ionization smoke detectors), stand-alone Simplex system (photo and ion), and the shipboard optical density meters (ODM) in the CSO at Locations A and B. Three prototypes were located at each location to determine the variation in the system. Figure 2 shows the locations of the detectors in the test area. The detectors at Location A were intended to be the primary fire detectors with the second set of detectors (Location B) providing additional information on detector sensitivity with respect to distance between the source and the detector. The extra sensors indicated in the figure are described in the next section. The exact locations of the detector groups are indicated in Table 8 and a visual indication is provided in Fig. 2.

Table 8. Locations in CSO (measured from aft, port corner of CSO to the center of each array).

Detector Group	*Distance forward (m [ft])*	*Distance starboard (m [ft])*	*Radial Distance from Source Location 2 (m [ft])*	*Radial Distance from Source Location 3 (m [ft])*
EWFD 1	2.8 (9.3)	5.1 (16.8)	1.3 (4.3)	4.5 (14.8)
EWFD 2	6.8 (22.2)	5.3 (17.3)	5.2 (17.2)	7.2 (23.5)
EWFD 3	2.8 (9.3)	4.6 (15.2)	1.3 (4.3)	4.1 (13.3)
EWFD 4	6.8 (22.2)	4.8 (15.7)	5.2 (17.2)	6.9 (22.6)
EWFD 5	3.1 (10.2)	4.6 (15.2)	1.6 (5.2)	4.2 (13.7)
EWFD 6	6.8 (22.2)	5.8 (19)	5.3 (17.4)	7.5 (24.6)
SAM Detect / First Alert	2.6 (8.5)	4.8 (15.8)	1.1 (3.5)	4.1 (13.6)
COTS A	2.8 (9.3)	4.2 (13.8)	1.5 (4.8)	3.7 (12.1)
SIMPLEX A	3.4 (11.2)	4.2 (13.8)	2.0 (6.5)	4.0 (16.2)
ODM A	3.4 (11.2)	5.1 (16.7)	1.9 (6.2)	4.7 (15.5)
COTS B	6.8 (22.2)	4.4 (14.3)	5.3 (17.2)	6.7 (21.9)
SIMPLEX B	7.0 (23.1)	4.4 (14.3)	5.5 (18.2)	6.9 (22.7)
ODM B	7.0 (23.1)	5.3 (17.3)	5.5 (18.1)	7.4 (24.3)
Source Location 2	1.5 (4.9)	4.9 (16)	-	-
Source Location 3	1.0 (3.3)	1.0 (3)	-	-

Notes:

- All locations represent the approximate center of each detector or group of detectors.

5.3 Additional Instrumentation

The performance of the prototype fire detectors was compared to the performance of the conventional ionization and photoelectric smoke detectors currently installed onboard ship (to be referred to as COTS Simplex system or COTS). The shipboard system consisted of Simplex ionization detectors (Model 4098-9717) and Simplex photoelectric detectors (Model 4098-9714) monitored with a single alarm panel (Simplex Model 4020). This fire alarm system provided time of alarm data for the exposed detectors. The alarm verification feature was not enabled. Despite previous statements [2,4,5] it was discovered that the shipboard system was not using alarm verification for any of the test series that were part of this program. However, observations of detector reactions during various tests seemed to indicate that this feature was not in operation. The alarm sensitivity of these detectors was set to 8%/m (2.5%/ft) for photoelectric and 4.2 %/m (1.3 %/ft) for ionization, which have been the settings of operation since installation.

Additional sensors were included for data collection, analysis and future algorithm development. A list of these sensors is included in Table 9. The additional Simplex detectors were used with a specially designed hardware/software package, which polled the detectors every 4 to 5 seconds and saved the data to a computer file. Based on experimental data, the detector outputs can be correlated to percent obscuration measurements, thus providing transient smoke detector output data. The additional Simplex detectors will be referred to in this report as the Simplex detectors, where as the permanently installed system on the ship is referred to as the COTS system. As noted in Table 9, several measurements were recorded by the Masscomp based data acquisition system onboard the Shadwell. Masscomp logic switches were also activated to record key events during the test. The activation of logic switches is detailed on the test sheets (see Appendix A).

Three video cameras were installed as shown in Fig. 1. Camera 2 positioned to view the smoke development from the source and spread across the overhead toward the detecto rs. Cameras 1 and 3 were used primarily for viewing the spread of smoke in the overhead at the locations of the detectors.

Table 9. Additional Sensors to Be Mounted with Prototype Detectors.

No.	*Species*	***Data Acquisition***	*Location*	*Instrument Model No.*	*Manufacturer*
1	Residential ionization smoke detector with standard housing (RION1)	LabView	Location A	83R	First Alert
2	Thermocouples	LabView	Location A, B and over Source Location 2	Type K	Omega
3	Thermocouples	Masscomp	2-25-2, 0.15 m above deck and 0.15 m below overhead	Type K, 0.127 mm bare bead	Omega
4	Optical Density Meter	Masscomp	Location A and B	880 nm laser with photodiode	TSI
5	Carbon Monoxide	Masscomp	Location A and B	NGA 2000, 0.25% range, unit 502 at A and unit 512 at B	Rosemount
6	Carbon Dioxide	Masscomp	Location A and B	NGA 2000, 0.5% range at A and B	Rosemount
7	Logic Switches for test events	Masscomp	Control Room		
8	Simplex photoelectric and ionization smoke detectors	ULTester	Location A and B	Ion: 4098-9717 Photo: 4098-9714	Simplex
9	SamDetect™	SamDetect software on a PC	Location A	SamDetect B1	RST, DaimlerChrysler

6.0 PROCEDURE AND SAFETY

Prior to each test, the test area was cleared of all personnel not involved with testing from frames 15 to 29 on the second deck. All designated hatches and doors were closed, and the prescribed ventilation was set. After completion of these tasks, test personnel were positioned in the appropriate locations. When the fuel package was prepared and the safety team in position, data collection and videos were initiated. Following approximately 3 minutes of background data, either the fire was ignited, the nuisance activity initiated or the Calrod energized for the smoldering fire scenarios. During the test, visual observations and event data were collected. After the fire/nuisance activity was complete or all of the compartment's sensors had alarmed, the compartment was ventilated by opening the F-stop at 2-15-1 and WTD 2-29-0 and turning on the E1-15-1 fan. Data collection continued for 10 additional minutes to assess the recovery of the sensors following the event. Once the safety team deemed the test area safe for personnel without breathing protection, the test area was prepared for the next test. This preparation included any cleanup of the test area, equipment setup for the next test, and verification of instruments.

7.0 TEST SUMMARY AND RESULTS

This section provides a summary of all the tests conducted. Table 10 presents general information about each test, including descriptions, important test times, location, and additional notes about each test. Table 11 contains the external ambient conditions recorded at the beginning of each test. Tables 12, 13, and 14 show the individual sensor readings at alarm time for each of the prototypes and their classification performance. Additionally, the prototypes' sensor readings at the highest alarm probability level are shown when an alarm condition was not reached during a test. Tables 15, 16, and 17 provide alarm time and classification performance information for the Shadwell COTS, the additional Simplex system, and the First Alert residential ionization detector, respectively. Table 18 gives a summary of the tests conducted in this series, organized by flaming fire sources, smoldering fire sources, and nuisance sources.

Table 10. Test Description, Times, and Comments.

Test	Fire type	Brief Description	Loc.	Date	Mass-Comp Start Time	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Venti-lation start time	Vent time (secs after initiation)	Test Comments
089	fire, flaming	Heptane	3	7/24/00	9:29:42	9:30:12	9:33:34	202	9:42:46	752	Ventilation not operational. TPS exhaust was physically disconnected from Engineering Office. CO sensor on prototype #4 was replaced due to spurious behavior. New sensor SN was 647055-040.
091	fire, flaming	Pipe insulation and fuel oil	3	7/24/00	11:36:56	11:37:41	11:40:55	194	11:50:13	558	Background Averaging Time in LabView was mistakenly set to 12 seconds instead of 1 minute. Ventilation patched with flexible piping.
092	fire, flaming	Flaming bag of trash next to TODCO wallboard	3	7/24/00	13:04:53	13:06:19	13:10:21	242	13:15:39	318	Background Averaging Time in LabView was mistakenly set to 12 seconds instead of 1 minute. Re-ignition necessary 86 seconds after initial ignition becauses the trash bag flames went out. Only the trash was on fire during this test. Flames were at the wallboard, but it was not involved.
093	nuisance	Pop-Tarts toasting (8)	2	7/24/00	13:39:03	13:39:30	13:42:39	189	13:54:01	682	First 8 Pop-Tarts toasted for 272 seconds. Second 8 Pop-Tarts toasted for 266 seconds.
094	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	3	7/24/00	14:22:24	14:22:56	14:26:21	205	14:34:17	476	Laundry pile consisted of: 2 med HANES undershirts (100% cotton), 1 med Fruit of LOOM brief (90%cotton,10%poly), 1 large long sleeve shirt (100%cotton), 1 polo shirt (50% cotton, 50% poly), 1 dress size 42 (100% cotton). 4, 1m lengths of LSDSGU-14 cables used COTS computer was 6 seconds behind.
095	fire, smoldering	Long duration smoldering electrical cables	3	7/24/00	15:03:12	15:03:51	15:07:01	190	15:41:07	2046	LSDSGU-14 cable, 33cm in length Arc Welder set at 375A. Two conductors connected.
096	nuisance	Welding steel plate	2	7/25/00	7:53:40	7:55:04	7:59:32	268	8:10:44	672	7 rods welded in 10.5 minutes.
097	fire, flaming	Flaming electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	3	7/25/00	8:39:45	8:40:19	8:43:24	185	8:50:42	438	15 conductors energized @ 375A. Transition to open flaming : 159 seconds after initiation.

Table 10. Test Description, Times, and Comments. (continued)

Test	Fire type	Brief Description	Loc.	Date	Mass-Comp Start Time	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Venti-lation start time	Vent time (secs after initiation)	Test Comments
098	fire, flaming	Flaming bedding	3	7/25/00	9:19:40	9:20:14	9:23:28	194	9:35:10	702	2 sheets, blanket, cover, pillow, mattress, and ticking. 0.6m x 0.6m (2ft x 2ft). 2 pieces of crumpled newspaper on top of mattress and against the pillow (somewhat tucked under pillow)
099	fire, smoldering	Printed wire board (PWB) fire	2	7/25/00	11:21:44	11:22:19	11:25:28	189	12:16:32	3064	Two boards used during this test. First board failed to heat properly. Sustained arc appeared on the second board 424 seconds after it was energized. FR29 door opened briefly at 826 seconds after initiation. Door from Engineering Office to Por Passage opened briefly at 2022 seconds after initiation.
100a	nuisance	Normal Toasting (8 slices at a time, 24 total)	2	7/25/00	12:47:05	12:49:22	12:52:38	196	13:06:59	861	This test consists of the first 861 seconds of the toasting test, before the fire transitions into a smoldering fire source. The first 8 slices were toasted for 211 seconds. The second 8 slices were toasted for 180 seconds.
100b	fire, smoldering	Burning Toast	2	7/25/00	12:47:05	12:49:22	12:52:38	196	13:09:00	982	This test consists of the entire toasting test, including the smoldering fire.
101	fire, smoldering	BSI 6266 wire test	2	7/25/00	13:34:49	13:35:17	13:38:24	187	13:46:22	478	
102	nuisance	Burning popcorn	2	7/25/00	14:12:10	14:12:40	14:15:46	186	14:29:58	852	Nuisance source considered to end when the door to the microwave was opened (734 seconds after ignition)
103	fire, flaming	Heptane	3	7/25/00	15:00:56	15:01:28	15:04:38	190	15:15:20	1024	
104	fire, flaming	Flaming bedding	3	7/25/00	15:28:57	15:29:24	15:32:44	200	15:38:52	368	Gas sampling pump not operational. Calrod set to 75% Fast transition to flaming (158 seconds after initiation)
105	nuisance	Cutting Steel with acetylene torch	2	7/26/00	8:12:50	8:13:44	8:17:32	228	8:21:10	218	Logic #6 (Masscomp) not functioning. Cutting conducted for 180 seconds.
106	nuisance	Cigarette smoking	2	7/26/00	8:40:47	8:41:12	8:44:18	186	9:02:08	1070	Smokers standing and walking around. Generally in the vicintity of sensor location B. Total of 11 cigarettes and 2 cigars. Machinery running in well deck during ventilation. Gases from exhaust pulled into CSO, causing incr. In CO and CO2 levels. Smoking continued for 1026 seconds.
107	fire, flaming	Flaming bag of trash next to TODCO wallboard	3	7/26/00	9:29:58	9:30:39	9:33:56	197	9:37:36	220	Logic #4 (Ventilation) temporarily disabled.

Table 10. Test Description, Times, and Comments. (continued)

Test	Fire type	Brief Description	Loc.	Date	Mass-Comp Start Time	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Venti-lation start time	Vent time (secs after initiation)	Test Comments
108	fire, flaming	Pipe insulation and fuel oil	3	7/26/00	9:54:06	9:54:20	9:57:28	188	10:09:58	750	
109	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	3	7/26/00	11:20:16	11:20:48	11:24:08	200	11:31:04	416	Laundry pile consisted of: 1 med HANES undershirts (100% cotton), 1 med Fruit of LOOM brief (100%cotton), denim dress size 20 (100% cotton), med shirt (50% cotton, 50% acrylic), large acrylic sweater, rayon dress size 16
110	nuisance	Steel grinding	2	7/26/00	11:50:55	11:51:31	11:54:40	199	12:05:52	672	Grinding occurred for 500 seconds.
111	fire, smoldering	Smoldering electrical cable (LSTSGU-9 M24623/16-03UN))	3	7/26/00	12:27:56	12:29:19	12:32:26	187	13:44:20	4314	Energized 2 of 3 conductors. Fiberfrax insulation wrapped around cable ~2732 seconds after initiation. Switched to energizing 1 conductor 3947 seconds after ignition.
112	nuisance	Burning popcorn	2	7/26/00	14:06:10	14:06:43	14:09:49	181	14:22:02	733	
113	fire, flaming	Flaming electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	3	7/26/00	14:38:32	14:39:48	14:42:58	190	14:51:44	526	Energized 15 of 30 conductors @ 375A. 13 full sheets of newspaper crumpled and placed on the deck around cable. Flaming occurred 169 seconds after initiation.
114a	nuisance	Pop-Tarts toasting (8)	2	7/26/00	15:16:51	15:17:20	15:20:28	188	15:32:50	742	This test consists of the first 931 seconds of the pop-tart test, before it transitions into a smoldering fire source. The first set of 8 Pop-Tarts was toasted for 246 seconds. The seconds set of 8 Pop-Tarts was toasted for 233 seconds.
114b	fire, smoldering	Burning Pop-Tarts	2	7/26/00	15:16:51	15:17:20	15:20:28	188	15:40:02	1174	This test consists of the entire pop-tart test, including the smolering fire portion. The third set of Pop-Tarts were purposely burnt in the toasters.
115	nuisance	Cutting Steel with acetylene torch	2	7/27/00	7:41:03	7:41:37	7:44:45	188	7:48:27	222	1/8" thick steel plate, Torch tip #1. Cutting occurred for 188 seconds.

Table 10. Test Description, Times, and Comments. (continued)

Test	Fire type	Brief Description	Loc.	Date	Mass-Comp Start Time	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Venti-lation start time	Vent time (secs after initiation)	Test Comments
116	fire, flaming	Flaming bedding	3	7/27/00	8:03:56	8:04:08	8:07:21	193	8:17:55	634	Variac @ 60%, Flaming ignition 332 seconds after Calrod initiation
117	fire, smoldering	Printed wire board (PWB) fire	2	7/27/00	8:33:09	8:33:36	8:36:55	199	9:14:57	2282	Two boards used during this test. Amps went out on first board and a new one was installed and started at 634 seconds after initiation. Sustained arc appeared on second board 252 seconds after it was energized. Portable fan used to blow on source between 1554 seconds and 1880 seconds
118	fire, smoldering	BSI 6266 wire test	2	7/27/00	9:45:49	9:46:32	9:49:41	191	9:56:41	420	Two wires heated in this test. The first was subject to 6V, 28A for 60 seconds, the second was allowed to burn completely. The second wire was initiated at 114 seconds after initial initiation.
119	nuisance	Steel grinding	2	7/27/00	10:18:49	10:19:27	10:22:57	210	10:31:39	522	Grinding was done on top of a drum, standing instead of sitting. Grinding occurred for 484 seconds.
120	nuisance	Welding steel plate	2	7/27/00	10:46:57	10:47:23	10:50:33	190	11:02:07	694	Welding occurred for 664 seconds.
121	fire, smoldering	Long duration smoldering electrical cables	3	7/27/00	13:22:17	13:22:58	13:26:43	225	14:18:11	3088	Cables on rack, ~1 ft above deck. After each connected cable stopped smoking, a new cable and/or conductor was hooked up. Each time the welder was turned back on, it was at a lower power level. The duration of energizing was: Cable 1-- 100% (602sec), 75% (124 sec), 50%(70 sec), Cable 2 - 40%(109 sec), 30%(58 sec), 20%(177 sec)
122	fire, smoldering	Smoldering electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	3	7/27/00	14:31:45	14:32:12	14:35:17	185	14:42:23	426	375A, set to 50% power. 7 sheets of crumpled newspaper on deck around cable. Flaming ignition occurred 388 seconds after initiation.
123	fire, smoldering	Smoldering Box w/ Packing	3	7/27/00	15:02:27	15:03:08	15:06:15	187	15:44:25	2290	Calrod initially set to 40%, then 80%(1179 seconds after initiation), 60% (1379 seconds after initiation), and 80% (1994 seconds after initiation). Flaming occurred 2133 seconds after initiation.
124	fire, smoldering	Smoldering bedding	3	7/28/00	7:29:04	7:29:43	7:32:57	194	9:09:47	5810	0.6m x 0.6m (2ft x 2ft) sample size. Calrod initially set to 40%, increased to 60% 5146 seconds after initation, and 80% 5463 seconds after initation.

Table 10. Test Description, Times, and Comments. (continued)

Test	*Fire type*	*Brief Description*	*Loc.*	*Date*	*Mass-Comp Start Time*	*DAQ Start time*	*Ignition / Initiation time*	*Ignition / Initiation Time (sec)*	*Venti-lation start time*	*Vent time (secs after initiation)*	*Test Comments*
125	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trashcan	3	7/28/00	10:33:00	10:33:40	10:36:51	191	11:20:41	2630	Calrod set to 40%.
126	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	3	7/28/00	12:17:05	12:17:34	12:20:43	189	13:07:45	2822	Bundle of 30 cables with Calrod in the middle. Calrod set to 40%, then 50% (440 seconds after initiation), 60% (838 seconds after initiation), 70%(2017 seconds after Initation), and 100%(2718 seconds after initation).

Table 11. Test Outside Ambient Conditions

Test	Fire type	Brief Description	Ambient Conditions			
			Temperature (°F)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction (°)
089	fire, flaming	Heptane	75	85	8	347
091	fire, flaming	Pipe insulation and fuel oil	83	65	6	300
092	fire, flaming	Flaming bag of trash next to TODCO wallboard	86	56	5	316
093	nuisance	Pop-Tarts toasting (8)	87	54	5	320
094	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	88	52	6	330
095	fire, smoldering	Long duration smoldering electrical cables	89	44	7	1
096	nuisance	Welding steel plate	74	77	7	322
097	fire, flaming	Flaming electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	75	81	7	329
098	fire, flaming	Flaming bedding	77	79	4	349
099	fire, smoldering	Printed wire board (PWB) fire	85	67	6	40
100a	nuisance	Normal Toasting (8 slices at a time, 24 total)	90	52	1	127
100b	fire, smoldering	Burning Toast	90	52	1	127
101	fire, smoldering	BSI 6266 wire test	89	51	4	91
102	nuisance	Burning popcorn	89	50	7	130
103	fire, flaming	Heptane	90	43	9	145
104	fire, flaming	Flaming bedding	N/A	N/A	4	133
105	nuisance	Cutting Steel with acetylene torch	78	95	6	61
106	nuisance	Cigarette smoking	79	91	7	41
107	fire, flaming	Flaming bag of trash next to TODCO wallboard	82	85	10	103
108	fire, flaming	Pipe insulation and fuel oil	83	79	11	100
109	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	84	76	7	105
110	nuisance	Steel grinding	86	68	5	150
111	fire, smoldering	Smoldering electrical cable (LSTSGU-9 M24623/16-03UN))	87	69	10	175
112	nuisance	Burning popcorn	84	73	19	122
113	fire, flaming	Flaming electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	84	78	17	127
114a	nuisance	Pop-Tarts toasting (8)	84	75	16	149

Table 11. Test Outside Ambient Conditions (continued)

Test	Fire type	Brief Description	Ambient Conditions			
			Temper-ature (°F)	*Relative Humidity (%)*	*Wind Speed (mph)*	*Wind Direction (°)*
114b	fire, smoldering	Burning Pop-Tarts	84	75	16	149
115	nuisance	Cutting Steel with acetylene torch	75	N/A	3	NDT
116	fire, flaming	Flaming bedding	76	95	4	63
117	fire, smoldering	Printed wire board (PWB) fire	79	88	3	47
118	fire, smoldering	BSI 6266 wire test	80	85	5	37
119	nuisance	Steel grinding	84	76	5	37
120	nuisance	Welding steel plate	83	75	4	24
121	fire, smoldering	Long duration smoldering electrical cables	86	65	7	144
122	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	89	58	7	6
123	fire, smoldering	Smoldering Box w/ Packing	87	63	11	154
124	fire, smoldering	Smoldering bedding	75	96	2	328
125	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trash can	N/A	N/A	N/A	N/A
126	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	85	72	5	137

Table 12. EWFD Prototypes 1 and 2 Alarm Response Information

Test	Fire type	Brief Description	EWFD 1 (Location A)									EWFD 2 (Location B)								
			Alarm Time (sec after initia-tion)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classifi-cation?	Alarm Time (sec after initia-tion)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Corrrect Classifi-cation?
089	fire, flaming	Heptane	215	32.4	0.4	2.3	48.6	36.3	1031.5	fire	Y	469	32.1	0.6	3.0	43.9	35.9	1258.6	fire	Y
091	fire, flaming	Pipe insulation and fuel oil	113	27.2	1.3	28.1	46.3	36.0	728.6	fire	Y	127	1.7	0.2	12.3	42.2	35.3	552.1	fire	Y
092	fire, flaming	Flaming bag of trash next to TODCO wallboard	181	47.7	2.9	62.5	46.4	36.5	964.4	fire	Y	217	17.7	1.5	62.1	42.9	35.3	796.5	fire	Y
093	nuisance	Pop-Tarts toasting (8)	611 (P= .9247)	34.4	0.1	0.8	43.7	37.2	651.8	-	Y	649 (P= .6907)	12.8	0.1	1.9	38.5	36.0	589.3	-	Y
094	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	141	40.4	0.3	10.7	45.0	36.5	785.3	fire	Y	159	5.6	0.2	9.4	42.1	35.2	551.9	fire	Y
095	fire, smoldering	Long duration smoldering electrical cables	1621 (P= .5578)	1.2	0.5	1.9	39.2	37.2	627.8	-	N	1747 (P= .5148)	2.6	0.4	-0.8	34.2	37.4	570.7	-	N
096	nuisance	Welding steel plate	119 (P= .7283)	2.3	0.8	11.7	40.3	35.7	754.1	-	Y	701 (P= .385)	9.4	0.5	10.3	34.3	35.8	644.6	-	Y

Table 12. EWFD Prototypes 1 and 2 Alarm Response Information (continued)

Test	Fire type	Brief Description	EWFD 1 (Location A)									EWFD 2 (Location B)								
			Alarm Time (sec after initia-tion)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classifi-cation?	Alarm Time (sec after initia-tion)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classifi-cation?
097	fire, flaming	Flaming electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	249	13.4	4.2	1.9	43.3	35.2	658.0	fire	Y	319	0.0	4.3	2.5	39.5	34.6	571.6	fire	Y
098	fire, flaming	Flaming bedding	67	32.6	0.3	15.0	48.1	35.1	738.4	fire	Y	91	4.8	0.2	10.6	43.0	34.6	607.8	fire	Y
099	fire, smoldering	Printed wire board (PWB) fire	2283 (P= .6673)	2.5	0.5	-0.3	51.3	36.1	730.5	-	N	2525 (P= .5485)	3.0	0.5	0.3	44.4	36.3	626.0	-	N
100 a	nuisance	Normal Toasting (8 slices at a time, 24 total)	413 (P= .3284)	23.0	0.1	-1.1	48.0	36.6	652.1	-	Y	157 (P= .1342)	-0.3	0.0	-0.5	43.4	35.4	510.5	-	Y
100 b	fire, smoldering	Burning Toast	809	64.9	5.1	4.1	46.8	37.3	687.2	fire	Y	903	30.4	4.8	17.6	44.1	36.4	626.5	fire	Y
101	fire, smoldering	BSI 6266 wire test	113	6.9	3.6	-1.1	41.9	36.7	637.9	fire	Y	379 (P= .2413)	1.5	0.2	-0.4	38.6	36.1	551.4	-	N
102	nuisance	Burning popcorn	787	1.8	2.2	13.0	40.5	37.5	653.2	post-nuisance	Y	551 (P= .5276)	0.2	0.3	0.8	36.1	36.6	551.5	-	Y
103	fire, flaming	Heptane	157	38.1	0.5	1.1	39.5	37.8	806.0	fire	Y	583	33.4	0.7	3.6	36.7	37.5	1122.0	fire	Y
104	fire, flaming	Flaming bedding	211	8.8	5.1	21.3	37.8	38.3	590.9	fire	Y	265	1.3	1.2	14.7	34.5	37.6	552.2	fire	Y

Table 12. EWFD Prototypes 1 and 2 Alarm Response Information (continued)

Test	Fire type	Brief Description	EWFD 1 (Location A)									EWFD 2 (Location B)								
			Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?
105	nuisance	Cutting Steel with acetylene torch	51	35.8	0.1	21.0	55.1	36.2	772.6	nuisance	N	83	8.1	0.1	17.2	52.4	35.0	608.3	nuisance	N
106	nuisance	Cigarette smoking	1307 (P= .6441)	-0.2	0.0	20.6	55.2	35.8	691.5	-	Y	1255 (P= .7803)	0.0	0.1	25.1	51.6	34.8	608.5	-	Y
107	fire, flaming	Flaming bag of trash next to TODCO wallboard	83	22.6	0.1	14.0	57.8	35.6	642.3	fire	Y	125	3.7	1.2	40.0	55.3	34.2	512.2	fire	Y
108	fire, flaming	Pipe insulation and fuel oil	73	13.8	1.1	18.8	55.8	35.8	617.2	fire	Y	119	1.1	0.1	13.1	53.5	34.6	491.9	fire	Y
109	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	111	20.9	0.1	12.0	51.4	36.5	596.0	fire	Y	187	3.3	0.0	21.4	48.9	35.1	511.0	fire	Y
110	nuisance	Steel grinding	391 (P= .8023)	29.2	0.3	4.3	50.0	36.7	629.1	-	Y	385 (P= .4205)	7.3	0.2	2.8	46.4	35.9	552.4	-	Y
111	fire, smoldering	Smoldering electrical cable (LSTSGU-9 M24623/16-03UN))	1097 (P= .4002)	2.1	0.2	19.0	49.6	37.1	631.2	-	N	1133 (P= .2779)	1.7	0.1	10.6	45.1	37.1	608.0	-	N

Table 12. EWFD Prototypes 1 and 2 Alarm Response Information (continued)

Test	Fire type	Brief Description	EWFD 1 (Location A)									EWFD 2 (Location B)								
			Alarm Time (sec after initia-tion)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classifi-cation?	Alarm Time (sec after initia-tion)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classifi-cation?
112	nuisance	Burning popcorn	377 (P= .734)	1.5	0.5	4.0	48.8	37.9	590.9	-	Y	615 (P= .4088)	1.0	0.2	6.6	44.4	37.4	533.0	-	Y
113	fire, flaming	Flaming electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	213	13.5	5.1	17.4	49.5	37.7	616.3	fire	Y	321	1.7	4.6	10.8	45.4	37.0	533.5	fire	Y
114 a	nuisance	Pop-Tarts toasting (8)	551 (P= .6875)	27.5	0.1	4.5	48.8	38.5	649.6	-	Y	635 (P= .2916)	6.7	0.1	6.0	46.6	37.3	608.5	-	Y
114 b	fire, smoldering	Burning Pop-Tarts	893	67.8	1.2	12.6	47.9	39.2	668.9	fire	Y	1131	60.1	4.8	32.9	46.3	38.0	664.8	fire	Y
115	nuisance	Cutting Steel with acetylene torch	55	31.6	0.1	16.4	58.1	33.5	734.1	nuisance	N	85	11.7	0.2	15.3	51.1	33.7	552.6	nuisance	N
116	fire, flaming	Flaming bedding	565	69.1	3.2	29.5	60.6	33.8	1114.2	fire	Y	449	0.9	1.4	14.2	53.9	32.9	511.8	fire	Y
117	fire, smoldering	Printed wire board (PWB) fire	1555 (P= .8187)	8.8	2.7	7.1	59.6	34.0	656.3	-	N	2239 (P= .4666)	5.0	1.2	8.2	51.8	34.1	552.1	-	N
118	fire, smoldering	BSI 6266 wire test	97 (P= .8238)	1.6	1.2	1.4	60.8	33.8	643.6	-	N	399 (P= .268)	0.7	0.2	2.8	54.2	33.5	533.5	-	N

Table 12. EWFD Prototypes 1 and 2 Alarm Response Information (continued)

Test	Fire type	Brief Description	EWFD 1 (Location A)									EWFD 2 (Location B)								
			Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Corrrect Classification?	Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Corrrect Classification?
119	nuisance	Steel grinding	165 (P= .7437)	29.1	0.5	1.5	59.2	34.0	599.9	-	Y	409 (P= .4457)	3.4	0.4	2.2	53.9	33.3	491.5	-	Y
120	nuisance	Welding steel plate	165 (P= .7941)	43.9	3.2	5.7	58.5	34.2	635.0	-	Y	399 (P= .5588)	4.2	1.1	3.4	52.4	33.7	510.0	-	Y
121	fire, smoldering	Long duration smoldering electrical cables	3069 (P= .4174)	4.8	0.5	7.4	49.9	36.5	705.5	-	N	2979 (P= .3789)	3.4	0.5	7.4	43.5	36.8	664.2	-	N
122	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	253	42.0	5.1	28.7	47.2	36.7	596.7	fire	Y	311	3.0	4.8	4.4	42.2	36.6	551.8	fire	Y
123	fire, smoldering	Smoldering Box w/ Packing	2169	59.4	5.1	78.3	51.9	37.2	667.8	fire	Y	2187	28.3	4.8	77.5	44.0	37.6	625.5	fire	Y
124	fire, smoldering	Smoldering bedding	2983	2.7	0.4	20.7	59.4	34.6	773.5	fire	Y	4519	8.8	1.5	30.1	50.1	35.2	742.3	fire	Y
125	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trashcan	1861	0.6	0.4	29.5	56.6	35.0	655.5	fire	Y	2395	4.5	0.5	68.4	49.2	35.3	607.7	fire	Y

Table 12. EWFD Prototypes 1 and 2 Alarm Response Information (continued)

Test	Fire type	Brief Description	EWFD 1 (Location A)									EWFD 2 (Location B)								
			Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?
126	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	1571	0.4	1.1	27.0	52.1	35.7	651.0	fire	Y	2821 (P= .8159)	8.6	2.7	37.3	44.0	36.4	626.3	-	N

Table 13. EWFD Prototypes 3 and 4 Alarm Response Information

Test	Fire type	Brief Description	EWFD 3 (Location A)									EWFD 4 (Location B)								
			Alarm Time (sec after initia-tion)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classifi-cation?	Alarm Time (sec after initia-tion)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Corrrect Classifi-cation?
089	fire, flaming	Heptane	247	33.9	0.5	2.7	40.6	35.8	1009.5	fire	Y	331	33.4	0.5	1.8	40.5	36.2	926.7	fire	Y
091	fire, flaming	Pipe insulation and fuel oil	111	19.4	0.7	32.4	38.4	35.9	733.8	fire	Y	155 (P= .8256)	13.0	1.0	15.5	37.6	36.0	498.8	-	N
092	fire, flaming	Flaming bag of trash next to TODCO wallboard	153	48.5	0.9	54.0	38.9	36.1	815.7	fire	Y	161	27.2	0.7	18.9	38.0	36.0	564.8	fire	Y
093	nuisance	Pop-Tarts toasting (8)	617 (P= .7245)	30.7	0.2	0.7	35.8	37.0	434.5	-	Y	639 (P= .3838)	9.0	0.0	1.6	33.8	36.7	429.3	-	Y
094	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	133	30.1	0.2	13.0	37.1	36.2	843.4	fire	Y	173	23.7	0.2	7.3	36.6	36.4	914.1	fire	Y
095	fire, smoldering	Long duration smoldering electrical cables	1611	0.7	0.0	12.4	31.4	36.9	452.0	fire	Y	1809 (P= .6302)	1.9	0.6	0.3	29.0	38.0	411.1	-	N
096	nuisance	Welding steel plate	637 (P= .6882)	34.8	1.3	16.1	32.9	35.7	622.9	-	Y	681 (P= .5348)	5.5	0.4	8.4	29.8	36.3	519.7	-	Y

Table 13. EWFD Prototypes 3 and 4 Alarm Response Information (continued)

Test	Fire type	Brief Description	EWFD 3 (Location A)									EWFD 4 (Location B)								
			Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?
097	fire, flaming	Flaming electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	211	8.9	2.9	0.5	35.0	35.4	424.5	fire	Y	309	4.7	4.9	1.8	35.6	35.2	491.6	fire	Y
098	fire, flaming	Flaming bedding	61	31.6	0.5	14.4	40.2	35.1	674.6	fire	Y	95	19.5	0.4	10.9	39.2	35.2	837.1	fire	Y
099	fire, smoldering	Printed wire board (PWB) fire	1993 (P=.6556)	0.8	0.3	-1.6	45.1	35.6	584.0	-	N	2165 (P=.5221)	1.2	0.3	-0.6	41.7	36.5	566.4	-	N
100 a	nuisance	Normal Toasting (8 slices at a time, 24 total)	663 (P=.3229)	22.0	0.1	-1.5	39.9	36.7	507.0	-	Y	183 (P=.1527)	0.5	0.1	-0.8	37.5	36.4	467.9	-	Y
100 b	fire, smoldering	Burning Toast	807	56.6	3.3	3.6	39.5	37.1	530.6	fire	Y	901	19.4	5.8	9.8	39.6	37.0	534.1	fire	Y
101	fire, smoldering	BSI 6266 wire test	115 (P=.732)	4.3	1.5	-1.5	33.9	36.6	454.5	-	N	477 (P=.3638)	2.6	0.4	-0.8	32.6	37.0	464.0	-	N
102	nuisance	Burning popcorn	787	-0.4	0.4	25.2	33.0	37.2	519.9	post-nuisance	Y	535 (P=.4696)	0.7	0.4	-0.1	30.8	37.4	446.9	-	Y
103	fire, flaming	Heptane	203	35.6	0.4	1.4	31.9	37.4	861.8	fire	Y	433	36.4	0.6	1.2	31.2	37.9	795.7	fire	Y
104	fire, flaming	Flaming bedding	213	0.3	0.0	19.7	30.2	38.0	455.0	fire	Y	277	7.5	3.6	14.6	28.9	38.3	475.0	fire	Y

Table 13. EWFD Prototypes 3 and 4 Alarm Response Information (continued)

Test	Fire type	Brief Description	EWFD 3 (Location A)									EWFD 4 (Location B)								
			Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?
105	nuisance	Cutting Steel with acetylene torch	49	32.8	0.2	16.6	45.4	36.3	757.5	nuisance	N	93	3.8	0.1	14.0	48.7	35.9	677.9	nuisance	N
106	nuisance	Cigarette smoking	1409 (P= .7232)	0.9	0.0	25.0	46.2	35.5	470.3	-	Y	1261 (P= .5914)	-1.3	0.0	17.5	47.4	35.7	521.1	-	Y
107	fire, flaming	Flaming bag of trash next to TODCO wallboard	75	11.7	0.1	14.6	48.9	35.3	542.8	fire	Y	121	18.0	0.0	20.0	50.6	35.1	595.3	fire	Y
108	fire, flaming	Pipe insulation and fuel oil	69	1.4	0.2	20.2	46.2	35.9	508.6	fire	Y	547	54.9	1.7	14.5	47.6	36.1	860.0	fire	Y
109	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	111	0.0	0.0	15.4	42.6	36.1	556.9	fire	Y	179	17.4	0.1	10.7	44.2	36.0	520.6	fire	Y
110	nuisance	Steel grinding	93 (P= .5203)	16.3	0.2	0.1	39.9	36.9	471.3	-	Y	649 (P= .4515)	10.9	0.1	2.7	40.5	37.0	501.1	-	Y
111	fire, smoldering	Smoldering electrical cable (LSTSGU-9 M24623/16-03UN))	1497 (P= .3666)	3.3	0.1	15.6	39.7	37.3	515.9	-	N	4137 (P= .5162)	-1.3	0.3	6.6	40.1	38.6	534.4	-	N

Table 13. EWFD Prototypes 3 and 4 Alarm Response Information (continued)

Test	Fire type	Brief Description	EWFD 3 (Location A)									EWFD 4 (Location B)								
			Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Corrrect Classification?	Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Corrrect Classification?
112	nuisance	Burning popcorn	369 (P= .6146)	1.0	0.3	2.3	39.7	37.7	474.2	-	Y	611 (P= .3832)	-0.1	0.4	4.2	39.4	38.0	468.1	-	Y
113	fire, flaming	Flaming electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	213	6.3	4.5	22.3	40.6	37.5	491.3	fire	Y	265	3.1	5.8	6.9	40.5	37.6	451.8	fire	Y
114 a	nuisance	Pop-Tarts toasting (8)	743 (P= .5826)	27.0	0.1	4.9	39.8	38.6	477.9	-	Y	359 (P= .2205)	1.9	0.1	1.6	41.6	37.7	478.2	-	Y
114 b	fire, smoldering	Burning Pop-Tarts	831	39.7	0.4	7.6	39.5	38.8	562.9	fire	Y	1117	58.9	5.7	21.2	41.7	38.5	573.6	fire	Y
115	nuisance	Cutting Steel with acetylene torch	59	19.6	0.0	14.6	49.7	33.3	697.6	nuisance	N	105	3.5	0.1	14.6	49.4	33.8	659.3	nuisance	N
116	fire, flaming	Flaming bedding	403	-0.2	1.6	11.2	51.4	33.4	492.0	fire	Y	499	19.7	3.0	16.8	51.6	33.7	588.0	fire	Y
117	fire, smoldering	Printed wire board (PWB) fire	1563 (P= .6332)	8.6	1.7	6.2	50.6	33.8	500.7	-	N	1695 (P= .4706)	3.9	1.0	5.3	50.1	34.4	527.4	-	N
118	fire, smoldering	BSI 6266 wire test	125 (P= .8383)	3.3	0.4	1.1	51.7	33.8	512.7	-	N	305 (P= .272)	1.0	0.1	1.5	51.7	34.1	510.8	-	N

Table 13. EWFD Prototypes 3 and 4 Alarm Response Information (continued)

Test	Fire type	Brief Description	EWFD 3 (Location A)									EWFD 4 (Location B)								
			Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?
119	nuisance	Steel grinding	49 (P= .8545)	1.7	0.5	-0.9	51.0	33.7	381.4	-	Y	227 (P= .6878)	1.0	0.4	0.0	51.8	33.8	466.5	-	Y
120	nuisance	Welding steel plate	225 (P= .8021)	36.9	3.6	4.5	49.8	34.1	535.2	-	Y	303 (P= .7737)	0.6	0.6	1.2	49.2	34.5	468.6	-	Y
121	fire, smoldering	Long duration smoldering electrical cables	2953 (P= .4961)	5.4	0.6	7.0	41.5	36.4	548.5	-	N	1323 (P= .3941)	1.5	0.3	3.7	40.6	36.8	535.2	-	N
122	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	245	16.9	4.5	35.1	39.2	36.3	482.5	fire	Y	277	2.3	5.8	2.0	37.3	37.1	460.0	fire	Y
123	fire, smoldering	Smoldering Box w/ Packing	2167	54.0	4.5	83.1	42.5	37.3	725.6	fire	Y	2183	57.0	5.8	50.2	38.9	38.0	572.9	fire	Y
124	fire, smoldering	Smoldering bedding	3457	21.2	1.9	38.7	50.5	34.7	661.0	fire	Y	5607	19.8	5.5	44.1	46.9	35.8	741.6	fire	Y
125	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trashcan	2201	17.8	4.5	74.0	47.2	35.0	571.1	fire	Y	2215	2.6	4.5	18.7	45.4	35.7	551.6	fire	Y

Table 13. EWFD Prototypes 3 and 4 Alarm Response Information (continued)

Test	Fire type	Brief Description	EWFD 3 (Location A)									EWFD 4 (Location B)								
			Alarm Time (sec after initiation)	*Ion Level (ΔMIC)*	*Photo Level (%/ft)*	*CO (ppm)*	*Relative Humidity (%)*	*RTD Temp (°C)*	*CO_2 (ppm)*	*Test Phase @ Alarm*	*Correct Classification?*	*Alarm Time (sec after initiation)*	*Ion Level (ΔMIC)*	*Photo Level (%/ft)*	*CO (ppm)*	*Relative Humidity (%)*	*RTD Temp (°C)*	*CO_2 (ppm)*	*Test Phase @ Alarm*	*Correct Classification?*
126	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	1901	12.7	4.5	58.7	42.4	35.8	555.8	fire	Y	2805 (P= .7097)	10.1	3.7	33.3	40.2	36.8	555.0	-	N

Table 14. EWFD Prototypes 5 and 6 Alarm Response Information

Test	Fire type	Brief Description	EWFD 5 (Location A)									EWFD 6 (Location B)								
			Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Corrrect Classification?	Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Corrrect Classification?
089	fire, flaming	Heptane	83	29.2	0.4	3.2	41.2	35.5	840.6	fire	Y	245	33.2	0.5	2.3	41.2	35.3	902.8	fire	Y
091	fire, flaming	Pipe insulation and fuel oil	59	14.9	1.6	25.3	38.8	35.5	458.1	fire	Y	123	2.7	0.2	17.2	39.0	35.0	458.8	fire	Y
092	fire, flaming	Flaming bag of trash next to TODCO wallboard	127	33.8	1.7	33.0	39.5	35.8	510.5	fire	Y	159	10.4	0.3	18.3	38.7	35.1	473.6	fire	Y
093	nuisance	Pop-Tarts toasting (8)	619 (P= .7942)	32.8	0.2	2.0	36.5	36.7	463.4	-	Y	629 (P= .7764)	28.4	0.4	1.6	34.4	35.9	440.6	-	Y
094	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	121	34.8	0.2	13.7	37.1	36.0	1022.6	fire	Y	145	22.4	0.1	9.4	37.7	35.2	675.1	fire	Y
095	fire, smoldering	Long duration smoldering electrical cables	1609 (P= .7302)	0.5	0.1	8.5	32.1	36.8	431.7	-	N	1897 (P= .3901)	1.0	0.3	-0.1	29.6	37.1	418.0	-	N
096	nuisance	Welding steel plate	535 (P= .667)	34.9	1.8	15.4	34.6	34.9	624.8	-	Y	687 (P= .6751)	10.9	0.6	9.5	29.7	35.8	485.5	-	Y

Table 14. EWFD Prototypes 5 and 6 Alarm Response Information (continued)

Test	Fire type	Brief Description	EWFD 5 (Location A)									EWFD 6 (Location B)								
			Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?
097	fire, flaming	Flaming electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	259	16.0	6.8	3.5	37.1	34.2	452.4	fire	Y	327	1.1	3.9	2.1	35.1	34.7	460.2	fire	Y
098	fire, flaming	Flaming bedding	57	29.7	0.2	16.4	41.4	34.3	806.6	fire	Y	101	15.2	0.3	13.9	39.3	34.5	840.2	fire	Y
099	fire, smoldering	Printed wire board (PWB) fire	2419 (P= .5042)	1.8	0.4	1.2	44.2	35.5	567.3	-	N	2341 (P= .4942)	1.5	0.4	-0.3	42.0	35.7	490.1	-	N
100 a	nuisance	Normal Toasting (8 slices at a time, 24 total)	641 (P= .2748)	20.2	0.2	0.7	40.2	36.5	507.5	-	Y	513 (P= .2246)	11.7	0.2	-0.5	39.8	35.9	481.5	-	Y
100 b	fire, smoldering	Burning Toast	809	54.0	6.8	5.6	39.5	37.0	504.9	fire	Y	865	52.2	3.6	6.3	39.9	36.4	509.7	fire	Y
101	fire, smoldering	BSI 6266 wire test	91 (P= .8546)	1.2	1.3	0.4	35.6	36.2	450.2	-	N	489 (P= .2921)	3.2	0.2	-0.6	32.2	36.2	441.2	-	N
102	nuisance	Burning popcorn	785	-2.3	0.5	27.2	34.5	36.9	470.8	post-nuisance	Y	879 (P= .5954)	-2.4	0.4	1.2	32.2	36.8	452.7	-	Y
103	fire, flaming	Heptane	171	33.9	0.5	2.9	32.9	37.2	693.0	fire	Y	249	32.5	0.6	1.6	32.0	37.0	792.5	fire	Y
104	fire, flaming	Flaming bedding	211	1.6	5.8	20.9	31.4	37.5	393.7	fire	Y	267	1.8	-0.1	18.3	29.6	37.5	424.9	fire	Y

Table 14. EWFD Prototypes 5 and 6 Alarm Response Information (continued)

Test	Fire type	Brief Description	EWFD 5 (Location A)									EWFD 6 (Location B)								
			Alarm Time (sec after initia-tion)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Corrrect Classifi-cation?	Alarm Time (sec after initia-tion)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Corrrect Classifi-cation?
105	nuisance	Cutting Steel with acetylene torch	49	27.1	0.2	17.5	48.3	35.4	771.7	nuisance	N	75	23.8	0.0	16.1	48.9	35.1	546.4	nuisance	N
106	nuisance	Cigarette smoking	1303 (P= .6576)	0.1	0.0	20.6	47.6	35.7	499.4	-	Y	1375 (P= .7403)	-2.5	0.0	24.0	49.9	34.4	433.6	-	Y
107	fire, flaming	Flaming bag of trash next to TODCO wallboard	73	20.3	0.2	17.2	49.7	35.0	474.6	fire	Y	117	12.1	0.0	26.1	51.7	34.3	538.6	fire	Y
108	fire, flaming	Pipe insulation and fuel oil	63	7.9	1.5	22.0	47.6	35.4	444.9	fire	Y	117	3.0	0.2	14.0	50.1	34.5	521.5	fire	Y
109	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	107	1.5	0.3	15.6	44.5	35.6	439.2	fire	Y	179	9.0	0.0	22.1	45.5	35.1	579.4	fire	Y
110	nuisance	Steel grinding	405 (P= .741)	25.4	0.3	5.3	42.7	36.4	443.4	-	Y	1329 (P= .4497)	-0.5	0.0	4.9	43.1	35.3	357.8	-	Y
111	fire, smoldering	Smoldering electrical cable (LSTSGU-9 M24623/16-03UN))	1299 (P= .35)	1.0	0.1	15.9	42.5	36.5	481.9	-	N	1225 (P= .2246)	0.7	0.1	10.2	42.5	36.7	490.2	-	N

Table 14. EWFD Prototypes 5 and 6 Alarm Response Information (continued)

Test	Fire type	Brief Description	EWFD 5 (Location A)									EWFD 6 (Location B)								
			Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Corrrect Classification?	Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Corrrect Classification?
112	nuisance	Burning popcorn	379 (P= .7822)	1.6	0.6	5.1	42.3	37.0	428.8	-	Y	591 (P= .4676)	-0.1	0.0	9.0	40.6	37.4	418.3	-	Y
113	fire, flaming	Flaming electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	209	10.8	6.8	19.7	42.7	37.0	463.6	fire	Y	403	6.4	6.3	8.5	41.1	37.0	422.4	fire	Y
114 a	nuisance	Pop-Tarts toasting (8)	547 (P= .5857)	25.0	0.0	5.5	41.3	37.9	489.3	-	Y	611 (P= .4703)	17.9	0.1	4.6	42.6	37.3	491.3	-	Y
114 b	fire, smoldering	Burning Pop-Tarts	983	71.9	4.0	21.4	40.7	38.8	503.3	fire	Y	895	39.9	0.3	10.0	42.7	37.7	504.8	fire	Y
115	nuisance	Cutting Steel with acetylene torch	57	26.8	0.0	15.6	51.5	32.6	619.9	nuisance	N	85	31.1	0.1	18.0	49.3	33.2	612.6	nuisance	N
116	fire, flaming	Flaming bedding	391	1.7	6.8	21.6	52.3	32.7	461.0	fire	Y	455	2.1	0.1	11.5	51.3	33.0	454.9	fire	Y
117	fire, smoldering	Printed wire board (PWB) fire	1011 (P= .69)	2.7	0.5	5.2	53.0	33.0	543.2	-	N	2287 (P= .4772)	6.6	1.1	7.3	49.3	33.9	495.3	-	N
118	fire, smoldering	BSI 6266 wire test	99 (P= .8546)	1.7	0.8	2.6	53.4	33.0	488.8	-	N	191 (P= .2619)	0.0	0.1	1.3	52.5	33.2	450.7	-	N

Table 14. EWFD Prototypes 5 and 6 Alarm Response Information (continued)

Test	Fire type	Brief Description	EWFD 5 (Location A)									EWFD 6 (Location B)								
			Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Ion Level (ΔMIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	RTD Temp (°C)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?
119	nuisance	Steel grinding	173 (P= .6841)	25.8	0.4	2.4	51.3	33.3	432.8	-	Y	253 (P= .646)	2.3	0.3	1.1	51.0	33.5	418.8	-	Y
120	nuisance	Welding steel plate	205 (P= .7326)	46.1	3.1	5.4	50.7	33.7	466.2	-	Y	729 (P= .6931)	32.5	1.2	5.8	48.1	34.1	503.4	-	Y
121	fire, smoldering	Long duration smoldering electrical cables	2957 (P= .5201)	3.4	0.7	8.0	44.0	35.7	552.9	-	N	2997 (P= .4524)	1.6	0.6	6.6	40.4	36.6	548.6	-	N
122	fire, smoldering	Smoldering electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	225	0.4	0.7	5.0	40.4	35.7	450.0	fire	Y	359	5.6	3.0	3.5	38.1	36.4	444.8	fire	Y
123	fire, smoldering	Smoldering Box w/ Packing	2157	46.8	6.8	63.0	43.2	36.5	557.0	fire	Y	2185	61.3	7.7	68.5	40.2	37.3	548.5	fire	Y
124	fire, smoldering	Smoldering bedding	3451	17.8	1.4	37.2	52.1	33.8	655.1	fire	Y	5653	25.8	5.5	53.5	47.1	35.1	693.7	fire	Y
125	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trashcan	2119	5.5	4.6	28.3	49.1	34.3	513.0	fire	Y	2335	4.2	7.0	29.3	46.6	34.9	505.9	fire	Y

Table 14. EWFD Prototypes 5 and 6 Alarm Response Information (continued)

Test	*Fire type*	*Brief Description*	*EWFD 5 (Location A)*									*EWFD 6 (Location B)*								
			Alarm Time (sec after initia-tion)	*Ion Level (ΔMIC)*	*Photo Level (%/ft)*	*CO (ppm)*	*Relative Humidity (%)*	*RTD Temp (°C)*	*CO_2 (ppm)*	*Test Phase @ Alarm*	*Correct Classifi-cation?*	*Alarm Time (sec after initia-tion)*	*Ion Level (ΔMIC)*	*Photo Level (%/ft)*	*CO (ppm)*	*Relative Humidity (%)*	*RTD Temp (°C)*	*CO_2 (ppm)*	*Test Phase @ Alarm*	*Correct Classifi-cation?*
126	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	2249	19.2	5.7	64.7	44.9	35.1	540.1	fire	Y	2883 (P= .7799)	7.7	3.7	33.5	41.4	36.0	516.9	-	N

Table 15. Shadwell COTS Alarm Response Information

Test	Fire type	Brief Description	COTS Ion (55) Location A			COTS Photo (56) Location A			COTS Ion (68) Location B			COTS Photo (54) Location B		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?
089	fire, flaming	Heptane	56	fire	Y	DNA	-	N	223	fire	Y	DNA	-	N
091	fire, flaming	Pipe insulation and fuel oil	46	fire	Y	88	fire	Y	151	fire	Y	421	fire	Y
092	fire, flaming	Flaming bag of trash next to TODCO wallboard	111	fire	Y	148	fire	Y	186	fire	Y	185	fire	Y
093	nuisance	Pop-Tarts toasting (8)	498	nuisance	N	DNA	-	Y	DNA	-	Y	DNA	-	Y
094	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	72	fire	Y	328	fire	Y	149	fire	Y	365	fire	Y
095	fire, smoldering	Long duration smoldering electrical cables	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
096	nuisance	Welding steel plate	238	nuisance	N	671	nuisance	N	DNA	-	Y	DNA	-	Y
097	fire, flaming	Flaming electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	DNA	-	N	227	fire	Y	DNA	-	N	248	fire	Y
098	fire, flaming	Flaming bedding	35	fire	Y	322	fire	Y	247	fire	Y	618	fire	Y
099	fire, smoldering	Printed wire board (PWB) fire	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
100 a	nuisance	Normal Toasting (8 slices at a time, 24 total)	437	nuisance	N	808	nuisance	N	DNA	-	Y	DNA	-	Y
100 b	fire, smoldering	Burning Toast	437	fire	Y	808	fire	Y	925	fire	Y	900	fire	Y
101	fire, smoldering	BSI 6266 wire test	DNA	-	N	303	fire	Y	DNA	-	N	DNA	-	N
102	nuisance	Burning popcorn	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
103	fire, flaming	Heptane	53	fire	Y	DNA	-	N	462	fire	Y	DNA	-	N
104	fire, flaming	Flaming bedding	188	fire	Y	205	fire	Y	301	fire	Y	268	fire	Y
105	nuisance	Cutting Steel with acetylene torch	45	nuisance	N	126	nuisance	N	DNA	-	Y	DNA	-	Y

Table 15. Shadwell COTS Alarm Response Information (continued)

Test	Fire type	Brief Description	COTS Ion (55) Location A			COTS Photo (56) Location A			COTS Ion (68) Location B			COTS Photo (54) Location B		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
106	nuisance	Cigarette smoking	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
107	fire, flaming	Flaming bag of trash next to TODCO wallboard	47	fire	Y	97	fire	Y	135	fire	Y	139	fire	Y
108	fire, flaming	Pipe insulation and fuel oil	44	fire	Y	323	fire	Y	374	fire	Y	603	fire	Y
109	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	77	fire	Y	282	fire	Y	232	fire	Y	328	fire	Y
110	nuisance	Steel grinding	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
111	fire, smoldering	Smoldering electrical cable (LSTSGU-9 M24623/16-03UN))	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
112	nuisance	Burning popcorn	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
113	fire, flaming	Flaming electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	189	fire	Y	205	fire	Y	DNA	-	N	234	fire	Y
114 a	nuisance	Pop-Tarts toasting (8)	467	nuisance	N	DNA	-	Y	DNA	-	Y	DNA	-	Y
114 b	fire, smoldering	Burning Pop-Tarts	467	fire	Y	971	fire	Y	1021	fire	Y	1096	fire	Y
115	nuisance	Cutting Steel with acetylene torch	39	nuisance	N	127	nuisance	N	DNA	-	Y	DNA	-	Y
116	fire, flaming	Flaming bedding	377	fire	Y	381	fire	Y	569	fire	Y	456	fire	Y
117	fire, smoldering	Printed wire board (PWB) fire	DNA	-	N	1597	fire	Y	DNA	-	N	DNA	-	N
118	fire, smoldering	BSI 6266 wire test	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
119	nuisance	Steel grinding	85	nuisance	N	DNA	-	Y	DNA	-	Y	DNA	-	Y
120	nuisance	Welding steel plate	167	nuisance	N	598	nuisance	N	DNA	-	Y	DNA	-	Y
121	fire, smoldering	Long duration smoldering electrical cables	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
122	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	190	fire	Y	248	fire	Y	353	fire	Y	244	fire	Y
123	fire, smoldering	Smoldering Box w/ Packing	2148	fire	Y	2152	fire	Y	2169	fire	Y	2173	fire	Y

Table 15. Shadwell COTS Alarm Response Information (continued)

Test	Fire type	Brief Description	COTS Ion (55) Location A			COTS Photo (56) Location A			COTS Ion (68) Location B			COTS Photo (54) Location B		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?
124	fire, smoldering	Smoldering bedding	5295	fire	Y	3521	fire	Y	DNA	-	N	2075	fire	Y
125	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trash can	2256	fire	Y	1856	fire	Y	2456	fire	Y	1718	fire	Y
126	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	DNA	-	N	1465	fire	Y	DNA	-	N	1465	fire	Y

Table 16. Additional Simplex System Alarm Response Information

Test	Fire type	Brief Description	Simplex Ion A			Simplex Photo A			Simplex Ion B			Simplex Photo B		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classifi-cation?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classifi-cation?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classifi-cation?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classifi-cation?
089	fire, flaming	Heptane	69	fire	Y	DNA	-	N	170	fire	Y	DNA	-	N
091	fire, flaming	Pipe insulation and fuel oil	56	fire	Y	135	fire	Y	342	fire	Y	478	fire	Y
092	fire, flaming	Flaming bag of trash next to TODCO wallboard	124	fire	Y	221	fire	Y	199	fire	Y	221	fire	Y
093	nuisance	Pop-Tarts toasting (8)	524	nuisance	N	DNA	-	Y	DNA	-	Y	DNA	-	Y
094	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	83	fire	Y	342	fire	Y	148	fire	Y	342	fire	Y
095	fire, smoldering	Long duration smoldering electrical cables	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
096	nuisance	Welding steel plate	496	nuisance	N	540	nuisance	N	DNA	-	Y	DNA	-	Y
097	fire, flaming	Flaming electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	DNA	-	N	254	fire	Y	DNA	-	N	263	fire	Y
098	fire, flaming	Flaming bedding	46	fire	Y	647	fire	Y	305	fire	Y	603	fire	Y
099	fire, smoldering	Printed wire board (PWB) fire	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
100 a	nuisance	Normal Toasting (8 slices at a time, 24 total)	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
100 b	fire, smoldering	Burning Toast	710	fire	Y	807	fire	Y	925	fire	Y	930	fire	Y
101	fire, smoldering	BSI 6266 wire test	DNA	-	N	339	fire	Y	DNA	-	N	DNA	-	N
102	nuisance	Burning popcorn	DNA	-	Y	410	nuisance	N	DNA	-	Y	DNA	-	Y
103	fire, flaming	Heptane	63	fire	Y	DNA	-	N	515	fire	Y	DNA	-	N
104	fire, flaming	Flaming bedding	203	fire	Y	322	fire	Y	304	fire	Y	322	fire	Y
105	nuisance	Cutting Steel with acetylene torch	60	nuisance	N	DNA	-	Y	122	nuisance	N	DNA	-	Y
106	nuisance	Cigarette smoking	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y

Table 16. Additional Simplex System Alarm Response Information (continued)

Test	Fire type	Brief Description	Simplex Ion A			Simplex Photo A			Simplex Ion B			Simplex Photo B		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?
107	fire, flaming	Flaming bag of trash next to TODCO wallboard	65	fire	Y	183	fire	Y	139	fire	Y	144	fire	Y
108	fire, flaming	Pipe insulation and fuel oil	60	fire	Y	393	fire	Y	512	fire	Y	595	fire	Y
109	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	91	fire	Y	306	fire	Y	249	fire	Y	310	fire	Y
110	nuisance	Steel grinding	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
111	fire, smoldering	Smoldering electrical cable (LSTSGU-9 M24623/16-03UN))	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
112	nuisance	Burning popcorn	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
113	fire, flaming	Flaming electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	205	fire	Y	262	fire	Y	DNA	-	N	244	fire	Y
114 a	nuisance	Pop-Tarts toasting (8)	504	nuisance	N	DNA	-	Y	DNA	-	Y	DNA	-	Y
114 b	fire, smoldering	Burning Pop-Tarts	504	fire	Y	952	fire	Y	1066	fire	Y	1136	fire	Y
115	nuisance	Cutting Steel with acetylene torch	67	nuisance	N	DNA	-	Y	141	nuisance	N	DNA	-	Y
116	fire, flaming	Flaming bedding	392	fire	Y	423	fire	Y	528	fire	Y	489	fire	Y
117	fire, smoldering	Printed wire board (PWB) fire	DNA	-	N	1563	fire	Y	DNA	-	N	2287	vent	N
118	fire, smoldering	BSI 6266 wire test	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
119	nuisance	Steel grinding	92	nuisance	N	DNA	-	Y	DNA	-	Y	DNA	-	Y
120	nuisance	Welding steel plate	148	nuisance	N	148	nuisance	N	DNA	-	Y	657	nuisance	N
121	fire, smoldering	Long duration smoldering electrical cables	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
122	fire, smoldering	Smoldering electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	240	fire	Y	301	fire	Y	358	fire	Y	244	fire	Y
123	fire, smoldering	Smoldering Box w/ Packing	2154	fire	Y	2171	fire	Y	2180	fire	Y	2176	fire	Y
124	fire, smoldering	Smoldering bedding	5641	fire	Y	5729	fire	Y	DNA	-	N	1788	fire	Y

Table 16. Additional Simplex System Alarm Response Information (continued)

Test	Fire type	Brief Description	Simplex Ion A			Simplex Photo A			Simplex Ion B			Simplex Photo B		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
125	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trash can	2344	fire	Y	2322	fire	Y	2533	fire	Y	1739	fire	Y
126	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	DNA	-	N	2902	vent	N	DNA	-	N	1279	fire	Y

Table 17. First Alert Residential Ionization Alarm Response Information

Test	Fire type	Brief Description	Residential Ion		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?
089	fire, flaming	Heptane	435	fire	Y
091	fire, flaming	Pipe insulation and fuel oil	129	fire	Y
092	fire, flaming	Flaming bag of trash next to TODCO wallboard	125	fire	Y
093	nuisance	Pop-Tarts toasting (8)	547	nuisance	N
094	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	233	fire	Y
095	fire, smoldering	Long duration smoldering electrical cables	DNA	-	N
096	nuisance	Welding steel plate	331	nuisance	N
097	fire, flaming	Flaming electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	DNA	-	N
098	fire, flaming	Flaming bedding	43	fire	Y
099	fire, smoldering	Printed wire board (PWB) fire	DNA	-	N
100 a	nuisance	Normal Toasting (8 slices at a time, 24 total)	DNA	-	Y
100 b	fire, smoldering	Burning Toast	715	fire	Y
101	fire, smoldering	BSI 6266 wire test	DNA	-	N
102	nuisance	Burning popcorn	DNA	-	Y
103	fire, flaming	Heptane	563	fire	Y
104	fire, flaming	Flaming bedding	285	fire	Y
105	nuisance	Cutting Steel with acetylene torch	45	nuisance	N
106	nuisance	Cigarette smoking	DNA	-	Y
107	fire, flaming	Flaming bag of trash next to TODCO wallboard	97	fire	Y
108	fire, flaming	Pipe insulation and fuel oil	167	fire	Y
109	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	157	fire	Y
110	nuisance	Steel grinding	DNA	-	Y
111	fire, smoldering	Smoldering electrical cable (LSTSGU-9 M24623/16-03UN))	DNA	-	N
112	nuisance	Burning popcorn	DNA	-	Y
113	fire, flaming	Flaming electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	269	fire	Y
114 a	nuisance	Pop-Tarts toasting (8)	DNA	-	Y

Table 17. First Alert Residential Ionization Alarm Response Information (continued)

Test	Fire type	Brief Description	Residential Ion		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?
114 b	fire, smoldering	Burning Pop-Tarts	777	fire	Y
115	nuisance	Cutting Steel with acetylene torch	47	nuisance	N
116	fire, flaming	Flaming bedding	463	fire	Y
117	fire, smoldering	Printed wire board (PWB) fire	DNA	-	N
118	fire, smoldering	BSI 6266 wire test	DNA	-	N
119	nuisance	Steel grinding	149	nuisance	N
120	nuisance	Welding steel plate	229	nuisance	N
121	fire, smoldering	Long duration smoldering electrical cables	DNA	-	N
122	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	331	fire	Y
123	fire, smoldering	Smoldering Box w/ Packing	2155	fire	Y
124	fire, smoldering	Smoldering bedding	5377	fire	Y
125	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trash can	2373	fire	Y
126	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	DNA	-	N

Table 18. Test Series Summary

Test	Scenario	Location	Brief Description
Flaming Fire Scenarios			
089	F01	3	Heptane
103	F01	3	Heptane
091	F02	3	Pipe insulation and fuel oil
108	F02	3	Pipe insulation and fuel oil
092	F06	3	Flaming bag of trash next to TODCO wallboard
107	F06	3	Flaming bag of trash next to TODCO wallboard
094	F07	3	Electrical cable and pipe insulation next to flaming laundry pile
109	F07	3	Electrical cable and pipe insulation next to flaming laundry pile
098	F10	3	Flaming bedding
104	F10	3	Flaming bedding
116	F10	3	Flaming bedding
097	F14	3	Flaming electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)
113	F14	3	Flaming electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)
Smoldering Fire Scenarios			
125	F04	3	Smoldering oily rag, newspaper, cardboard in sm. Trash can
095	F08	3	Long duration smoldering electrical cables
121	F08	3	Long duration smoldering electrical cables
111	F08	3	Long duration smoldering electrical cables
124	F09	3	Smoldering bedding
099	F11	2	Printed wire board (PWB) fire
117	F11	2	Printed wire board (PWB) fire
101	F13	2	BSI 6266 wire test
118	F13	2	BSI 6266 wire test
122	F14	3	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)
126	F14	3	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)
100b	F15	2	Burning Toast
114b	F16	2	Burning Pop-Tarts
123	F17	3	Smoldering Box w/ Packing
Nuisance Scenarios			
093	N01	2	Pop-Tarts toasting (8)
114a	N01	2	Pop-Tarts toasting (8)
096	N02	2	Welding steel plate
120	N02	2	Welding steel plate
105	N03	2	Cutting Steel with acetylene torch
115	N03	2	Cutting Steel with acetylene torch
102	N04	2	Burning popcorn
112	N04	2	Burning popcorn
106	N05	CSO	Cigarette smoking
100a	N06	2	Normal Toasting (8 slices at a time, 24 total)
110	N07	2	Steel grinding
119	N07	2	Steel grinding

8.0 ANALYSIS

This section discusses the results as they apply to the objectives of the test series. The section is divided into four main subsections: 1) Expanded Signature Data, 2) Prototype Performance, 3) Evaluation of Alternate Algorithms and 4) Improved Real-Time Execution and Data Transfer.

8.1 Expanded Signature Data

In this test series, 39 tests were conducted, increasing the size of the fire and nuisance source database. Although the objective was to primarily provide more replicate and complete data of scenarios previously evaluated, three new scenarios were formally incorporated into this test series. The "Burning Toast" and "Burning Pop-Tarts™" scenarios were simply extensions of the respective nuisance scenarios ("Normal Toasting" and "Toasting Pop-Tarts™"). The last set of bread or Pop-Tarts™ placed in the toasters was allowed to burn in order to generate a smoldering fire source. The other truly new scenario was a "Smoldering Box with Packing." This test utilized a Calrod to initiate smoldering combustion in a cardboard box filled with synthetic packaging material. The full set of data from this test series will serve as a validation data set of the alarm classification algorithm developed from the previous test series. The next sections provide analyses of the performance of the current real-time algorithm and alternate algorithms using the data set from this test series.

8.2 Prototype Performance

This section details the performance of the early warning prototype detection system. The discussion first presents a general evaluation of the response time performance of the detectors. This evaluation includes an analysis of all of the individual System Sensor and Simplex ionization and photoelectric detectors used in this test series as well as the prototypes as complete units. The second part of the discussion focuses on the performance of the detectors to correctly classify each fire and nuisance source.

8.2.1 Average Response Time

The response time of the prototype detectors was compared to the commercial photoelectric and ionization smoke detectors used in the test. These detectors included the two Simplex systems (referred to as COTS and Simplex, see Section 5.3) and the individual System Sensor photoelectric and ionization detectors that were part of each of the EWFD prototypes. As part of the post-test data investigation, the individual System Sensor photo and ion detectors were evaluated for their response times at various alarm levels. The average response times of the System Sensor detectors were compared to the Shadwell COTS detectors and additional Simplex detectors, which were co-located in the test compartment at Locations A and B. The response times were evaluated at alarm thresholds of 8%/m for photoelectric and 4.2%/m for ionization. The results for Locations A and B are presented in Tables 19 and 20, respectively. The System Sensor detectors are identified by the prototype number (1 to 6). The average response times indicated in the Tables are based on "common alarms" in each category for each set of detectors. Common alarms are simply defined as tests where the set of detectors all alarmed. For example, EWFD 2 photo, EWFD 4 photo, EWFD 6 photo, COTS B photo, and Simplex B photo recorded 8, 10, 9, 10, and 10 alarms, respectively, out of all 13 flaming fire tests. Out of these alarms, there were only 7 tests where all the detectors alarmed. Therefore, the average response time for each detector is based on these 7 "common alarms." Because each set of detectors is based on a different set of "common alarms" in each category, direct comparison of average response times between the detectors at different locations and between the detector sets is not possible. Note that the shaded elements represent the detector that had the fastest average response time in each category (this notation applies to all the tables in this section.). It is also noted that these average values provide only a general indication of the differences in response time. This fact is evidenced by the rather large standard deviations associated with each average.

Table 19. Summary of Average Response Times for Individual Smoke Detectors at Location A (in seconds after ignition/initiation)

	Location A Ion					Location A Photo				
	1	3	5	COTS	SIMPLEX	1	3	5	COTS	SIMPLEX
	4.2%/m	4.2%/m	4.2%/m	4.2%/m	4.2%/m	8%/m	8%/m	8%/m	8%/m	8%/m
all fire tests	782	817	784	672	725	840	794	759	757	1037
fire, flaming	201	259	211	108	121	303	309	251	237	317
fire, smoldering	1943	1931	1929	1799	1932	1684	1555	1558	1574	2169
nuisance	66	77	136	42	64	135	155	153	598	148

	# Common Alarm Tests, Location A Ion	# Common Alarm Tests, Location A Photo
all fire tests	18	18
fire, flaming	12	11
fire, smoldering	6	7
nuisance	2	1

Table 20. Summary of Average Response Times for Individual Smoke Detectors at Location B (in seconds after ignition/initiation)

	Location B Ion					Location B Photo				
	2	4	6	COTS	SIMPLEX	2	4	6	COTS	SIMPLEX
	4.2%/m	4.2%/m	4.2%/m	4.2%/m	4.2%/m	8%/m	8%/m	8%/m	8%/m	8%/m
all fire tests	837	760	715	709	759	1181	1074	1166	837	820
fire, flaming	408	302	261	242	301	369	323	349	293	312
fire, smoldering	1695	1677	1624	1643	1676	1993	1825	1983	1382	1327
nuisance	NCA	NCA	NCA	NCA	NCA	-	-	-	-	-

	# Common Alarm Tests, Location A Ion	# Common Alarm Tests, Location A Photo
all fire tests	12	14
fire, flaming	8	7
fire, smoldering	4	7
nuisance	0	0

"NCA" = no common alarms

"-" = No alarms

Tables 19 and 20 provide a comparison of the response times of the commercial smoke detectors. Based on Table 19 for Location A, the following observations can be made:

- All EWFD ion detectors performed similarly, as they generally responded within 60 seconds of each other for fire sources.
- All EWFD photo detectors responded within 85 seconds of each other, with the exception of the EWFD 1 photo, which took longer to respond to smoldering fire sources.
- The COTS ionization detector at Location A was clearly faster than the System Sensor detectors at this location. The COTS ion was only marginally better than the Simplex ion, but it responded more than 90 seconds on average faster to fire sources than all of the EWFD ion detectors. It also responded more than 2 minutes faster to smoldering fire sources than all the other commercial ion detectors at this location.
- Although the COTS photo responded faster, the differences between the photo detectors are smaller than for the ion detectors. The COTS photo was only 2 seconds faster on average than EWFD 5 photo for all the fire tests, and less than 15 seconds faster for flaming fire tests. EWFD 3 photo also recorded the fastest average response time to smoldering fire sources.
- The Simplex photo had an abnormally long response time at Location A, particularly for smoldering fire sources, where it averaged about 500 seconds slower than the other photo detectors.
- No meaningful conclusions can be drawn about the response time performance of the detectors in nuisance tests because there is a clear lack of tests where all detectors alarmed.

The primary conclusion to draw from the comparisons in Table 19 is that the COTS Simplex detectors (particularly the ionization unit) generally responded faster than the System Sensor detectors that were used in the EWFD prototypes. Consequently, comparisons of the EWFD prototypes to the COTS Simplex system does not provide a true assessment of the advantage that the multi-sensor, multi-criteria alarm algorithm provides beyond using the smoke detectors individually. A better comparison is made by contrasting the results of the prototypes to the System Sensor detectors that are used in the prototypes. If it had been possible to use the Simplex detectors in the prototypes, response times for the prototypes may have been faster due to the generally faster response to the smoke signatures. Comparisons of the EWFD prototypes to both the COTS Simplex detectors and the System Sensor detectors are presented below.

Tables 21 and 22 present the average response times of the EWFD prototypes compared to the response times of the COTS Simplex and additional Simplex detectors for Locations A and B, respectively. The "common alarm" method is also used in these Tables, so direct comparison of Location A and Location B performance is not possible. General observations from these two tables are as follows:

- Considering the case of all fire tests, the average response times of every EWFD prototype was faster than all of the COTS and Simplex detectors. This was true for both Locations A and B.

- The improved overall average response time performance is primarily for the smoldering fires. At Location A, the EWFD Prototypes responded faster on average to smoldering fire sources than the other detectors with one exception. The Simplex photoelectric detector at this location responded faster on average than EWFD Prototypes 3 and 5.

- The COTS and Simplex ion detectors were generally faster than the prototypes for flaming fires at Location A (i.e., closer to the source). However, at Location B (farther from the source) all of the prototypes were faster than the COTS and Simplex ion detectors for flaming fires.

Tables 23 and 24 present the average response times of the EWFD prototypes compared to the response times of the System Sensor ionization and photoelectric detectors for Locations A and B, respectively. The "common alarm" method is also used in these Tables, so direct comparison of Location A and Location B performance is not possible. In contrast to the comparison between the EWFD prototypes and the COTS and additional Simplex detectors, Tables 23 and 24 generally show faster EWFD response

Table 21. Summary of Average Response Times for EWFD Prototypes and Other Detectors at Location A (in seconds after ignition/initiation)

	EWFD 1	EWFD 3	EWFD 5	COTS Ion	COTS Photo	Simplex Ion	Simplex photo	Res. Ion
all fire tests	670	703	698	807	970	749	746	856
fire, flaming	176	154	142	133	323	119	238	197
fire, smoldering	1495	1618	1624	1932	2047	1799	1593	1955
nuisance	NCA	NCA	NCA	NCA	NCA	NCA	NCA	NCA

	# Common Alarm Tests
all fire tests	16
fire, flaming	10
fire, smoldering	6
nuisance	0

Table 22. Summary of Average Response Times for EWFD Prototypes and Other Detectors at Location B (in seconds after ignition/initiation)

	EWFD 2	EWFD 4	EWFD 6	COTS Ion	COTS Photo	Simplex Ion	Simplex photo
all fire tests	657	673	629	727	712	701	699
fire, flaming	202	257	193	298	378	274	370
fire, smoldering	1385	1339	1328	1412	1245	1385	1226
nuisance	NCA	NCA	NCA	NCA	NCA	NCA	NCA

	# Common Alarm Tests
all fire tests	13
fire, flaming	8
fire, smoldering	5
nuisance	0

"NCA" = no common alarms

Table 23. Summary of Average Response Times for Prototypes versus System Sensor detectors at Location "A" (in seconds after ignition/initiation)

	EWFD 1	EWFD 1 Ion	EWFD 1 Photo	EWFD 3	EWFD 3 Ion	EWFD 3 Photo	EWFD 5	EWFD 5 Ion	EWFD 5 Photo
All fire tests	670	844	830	703	867	789	698	842	748
Flaming fires	176	184	309	154	229	320	142	190	253
Smoldering fires	1495	1943	1698	1618	1931	1571	1624	1929	1573
nuisances	NCA	NCA	NCA	NCA	NCA	NCA	NCA	NCA	NCA
All fire tests	16			16			16		
Flaming fires	10			10			10		
Smoldering fires	6			6			6		
nuisances	0			0			0		

Table 24. Summary of Average Response Times for Prototypes versus System Sensor detectors at Location "B" (in seconds after ignition/initiation)

	EWFD 2	EWFD 2 Ion	EWFD 2 Photo	EWFD 4	EWFD 4 Ion	EWFD 4 Photo	EWFD 6	EWFD 6 Ion	EWFD 6 Photo
All fire tests	815	927	911	754	798	802	1110	1203	1154
Flaming fires	144	313	419	268	296	391	198	300	379
Smoldering fires	1654	1695	1525	1604	1677	1520	2387	2466	2239
nuisances	NCA	NCA	NCA	NCA	NCA	NCA	NCA	NCA	NCA
All fire tests	9			11			12		
Flaming fires	5			7			7		
Smoldering fires	4			4			5		
nuisances	0			0			0		

"NCA" = no common alarms

times compared to the System Sensor ionization and photoelectric smoke detectors. Even for the flaming fires, the multi-criteria prototypes responded faster on average than the corresponding ionization detectors for all prototypes and at all locations.

At both the A and B locations, the prototypes did not typically respond faster than the System Sensor photoelectric detectors. However, all of the prototypes were faster on average than the System Sensor ionization detectors. As indicated in a number of the response time comparisons, the EWFD alarm algorithm has not responded as fast as desired compared to the commercial smoke detectors. There appears to be several reasons for this outcome. First, the training data set did not contain good examples of the new, long duration smoldering fires that were conducted in this test series. Second, the results from this test series have indicated that the current PNN may rely too heavily on signature rate of change values. Particularly as sources are located at a range of distances from the detectors and source intensities vary, there may be too much variability in the rate of change of some signatures. Besides evaluating the use of signature rates of change, another possible solution to improving smoldering fire response times is the use of a three-class PNN algorithm. Currently, the PNN uses a two-class approach, fires and nuisance sources. There have been other studies [14] that indicate that the use of increased number of classes (e.g., flaming, smoldering and nuisance for this case) may provide improved performance for each class.

8.2.2 Classification Performance

The performance of the EWFD prototypes to properly classify events is presented in Tables 25 to 28. The Tables are arranged to compare the prototype performance to both the COTS and Simplex detectors (Tables 25 and 26) and the System Sensor detectors (Tables 27 and 28). The classification performance of each detector is presented as the number of tests correctly classified with respect to each of five categories; Overall, Total Fires, Flaming Fires, Smoldering Fires, and Nuisances. It should be noted that the overall and fire classifications are not 100 percent for any detector; this is because some of the fires were of such small size and duration, that the detectors did not alarm. For the purpose of further analyzing the signature patterns from these very incipient sources, these tests have been included in the database. During further development of the prototypes, a minimum level of fire size may be identified, upon which these small fires will not be considered as sources to be detected by the EWFD system.

Table 25. Summary of Classification Performance of Detectors at Location A

	Overall Total, % correct	*Total Fires, % correct*	*Flaming Fires, % correct*	*Smoldering Fires, % correct*	*Nuisances, % correct*
EWFD 1	79.5 (31/39)	77.8 (21/27)	100.0 (13/13)	57.1 (8/14)	83.3 (10/12)
EWFD 3	79.5 (31/39)	77.8 (21/27)	100.0 (13/13)	57.1 (8/14)	83.3 (10/12)
EWFD 5	76.9 (30/39)	74.1 (20/27)	100.0 (13/13)	50.0 (7/14)	83.3 (10/12)
Simplex Ion A	59.0 (23/39)	66.7 (18/27)	92.3 (12/13)	42.9 (6/14)	41.7 (5/12)
Simplex Photo A	71.8 (28/39)	70.4 (19/27)	84.6 (11/13)	57.1 (8/14)	75.0 (9/12)
COTS 55 Ion	56.4 (22/39)	66.7 (18/27)	92.3 (12/13)	42.9 (6/14)	33.3 (4/12)
COTS 56 Photo	69.2 (27/39)	74.1 (20/27)	84.6 (11/13)	64.3 (9/14)	58.3 (7/12)

Table 26. Summary of Classification Performance of Detectors at Location B

	Overall Total, % correct	*Total Fires, % correct*	*Flaming Fires, % correct*	*Smoldering Fires, % correct*	*Nuisances, % correct*
EWFD 2	74.4 (29/39)	70.4 (19/27)	100.0 (13/13)	42.9 (6/14)	83.3 (10/12)
EWFD 4	71.8 (28/39)	66.7 (18/27)	92.3 (12/13)	42.9 (6/14)	83.3 (10/12)
EWFD 6	74.4 (29/39)	70.4 (19/27)	100.0 (13/13)	42.9 (6/14)	83.3 (10/12)
Simplex Ion B	66.7 (26/39)	59.3 (16/27)	84.6 (11/13)	35.7 (5/14)	83.3 (10/12)
Simplex Photo B	74.4 (29/39)	66.7 (18/27)	84.6 (11/13)	50.0 (7/14)	91.7 (11/12)
COTS 68 Ion	71.8 (28/39)	59.3 (16/27)	84.6 (11/13)	35.7 (5/14)	100.0 (12/12)
COTS 54 Photo	76.9 (30/39)	66.7 (18/27)	84.6 (11/13)	50.0 (7/14)	100.0 (12/12)

Table 27. Summary of Classification Performance of EWFD Prototypes and System Sensor Detectors at Location A

	Overall Total, % correct	Total Fires, % correct	Flaming Fires, % correct	Smoldering Fires, % correct	Nuisances, % correct
EWFD 1	79.5(31/39)	77.8 (21/27)	100.0 (13/13)	57.1 (8/14)	83.3 (10/12)
EWFD 1 Ion	66.7 (26/39)	66.7 (18/27)	92.3 (12/13)	42.9 (6/14)	66.7 (8/12)
EWFD 1 Photo	76.9 (30/39)	70.4 (19/27)	76.9 (10/13)	64.3 (9/14)	91.7 (11/12)
EWFD 3	79.5(31/39)	77.8 (21/27)	100.0 (13/13)	57.1 (8/14)	83.3 (10/12)
EWFD 3 Ion	71.8 (28/39)	66.7 (18/27)	92.3 (12/13)	42.9 (6/14)	83.3 (10/12)
EWFD 3 Photo	71.8 (28/39)	63.0 (17/27)	76.9 (10/13)	50.0 (7/14)	91.7 (11/12)
EWFD 5	76.9 (30/39)	74.1 (20/27)	100.0 (13/13)	50.0 (7/14)	83.3 (10/12)
EWFD 5 Ion	69.2 (27/39)	66.7 (18/27)	92.3 (12/13)	42.9 (6/14)	75.0 (9/12)
EWFD 5 Photo	74.4 (29/39)	66.7 (18/27)	76.9 (10/13)	57.1 (8/14)	91.7 (11/12)

Table 28. Summary of Classification Performance of EWFD Prototypes and System Sensor Detectors at Location B

	Overall Total, % correct	Total Fires, % correct	Flaming Fires, % correct	Smoldering Fires, % correct	Nuisances, % correct
EWFD 2	74.4 (29/39)	70.4 (19/27)	100.0 (13/13)	42.9 (6/14)	83.3 (10/12)
EWFD 2 Ion	51.3 (20/39)	37.0 (10/27)	46.2 (6/13)	28.6 (4/14)	83.3 (10/12)
EWFD 2 Photo	64.1 (25/39)	48.1 (13/27)	46.2 (6/13)	50.0 (7/14)	100.0 (12/12)
EWFD 4	71.8 (28/39)	66.7 (18/27)	92.3 (12/13)	42.9 (6/14)	83.3 (10/12)
EWFD 4 Ion	69.2 (27/39)	55.6 (15/27)	84.6 (11/13)	28.6 (4/14)	100.0 (12/12)
EWFD 4 Photo	74.4 (29/39)	63.0 (17/27)	76.9 (10/13)	50.0 (7/14)	100.0 (12/12)
EWFD 6	74.4 (29/39)	70.4 (19/27)	100.0 (13/13)	42.9 (6/14)	83.3 (10/12)
EWFD 6 Ion	64.1 (25/39)	55.6 (15/27)	84.6 (11/13)	28.6 (4/14)	83.3 (10/12)
EWFD 6 Photo	71.8 (28/39)	59.3 (16/27)	69.2 (9/13)	50.0 (7/14)	100.0 (12/12)

Tables 25 and 26 show the classification performance of the the EWFD prototypes compared to the COTS and Simplex detectors at Locations A and B, respectively. General observations about these classification results are:

- Overall, the EWFD prototypes performed better at Location A than at Location B when compared to other detectors at those locations. Because of the incipient nature of many of the sources, it is expected that the Location A detectors, which are closer to the sources, would have higher correct classification rates compared to the Location B detectors.

- At both locations, all EWFD prototypes correctly classified more total fires and flaming fires than the commercial smoke detectors.

- The performance of EWFD Prototypes in classifying smoldering fires was better than the ionization detectors and poorer than the photoelectric detectors at both locations.

- The Location A EWFD Prototypes rejected more nuisance sources than other Location A detectors.

Tables 27 and 28 present the classification performance of the EWFD Prototypes compared to the individual System Sensor smoke detectors installed on the Prototypes. Table 27 shows Location A, while Table 28 shows Location B. The following conclusions can be drawn from these Tables:

- With the exception of EWFD Prototype 4, all prototypes outperform the individual System Sensor detectors from the overall standpoint.

- All of the EWFD prototypes classified more fires than the individual System Sensor detectors when comparing the Total Fires and Flaming Fires values. This result indicates that the use of the multi-criteria algorithm provided greater sensitivity in detecting incipient fires than the commercial smoke detectors.

- With the exception of EWFD Prototype 3, the System Sensor photoelectric detectors performed better than the prototypes when classifying smoldering fire sources. As noted above, the detection of the long duration smoldering fires is an area of expected improvement for future alarm algorithms.

- The EWFD prototypes correctly classifed the same or more nuisance sources than the System Sensor ionization detectors, but fewer than the System Sensor photoelectric detectors.

8.3 Evaluation of Alternate Algorithms

As briefly stated in Section 5.22, the real-time deployment of the PNN required data acquisition, processing and transfer from LabVIEW to a dynamic link library (DLL) file. The vector of input sensor responses, one number for each sensor in the array, comprises the set of data that is passed to the algorithm for pre-processing and PNN analysis during the real-time deployment. For all prototypes the vector was four elements long (i.e., four sensor inputs). Preprocessing included background subtraction. Processing was done on all sensor values. The CO and CO_2 sensors were background subtracted with the values passed from the averaging of 60 seconds worth of data. The ionization detector outputs were converted from ΔMIC to percent obscuration/ft then to percent obscuration/m, and the photoelectric detector outputs were converted from percent obscuration/ft to percent obscuration/m, respectively. The resulting pattern (sensor vector) was added to the end of a 25x4 matrix, data_history, and the first row removed from the matrix to maintain the size of the matrix. In this manner new patterns were added and data_history was updated to reflect the twenty-five most recent patterns collected. The slopes of the responses were calculated using the 25 points in data_history. From data_history, the pattern magnitudes and slopes were then auto-scaled (mean zero and unit variance) using the means and standard deviations derived from the training set. The resulting pattern (a magnitude and slope for each sensor) was then submitted to the PNN algorithm for the classification and the probability of a fire event was determined. The alarm state was triggered if the probability was greater than 0.85 for three or more consecutive predictions.

The real-time analysis consisted of the sensor combination: ION, Photo, CO, CO_2, background subtraction using a 140-pattern training set generated at the 1.63% photoelectric alarm times, and data averaging of 10-point magnitude and 25-point slope [8]. Following each test, ten alternative approaches were evaluated. The sensor combinations, preprocessing method, training sets, training set criteria, and the number of points used to determine the magnitudes were all varied. The different combinations tested are shown in Table 29. The original prototypes used in Test Series 1 and 2 were also tested (see combinations 9 and 10). Table 30 describes the training sets evaluated.

Table 29. Sensor Combinations and Algorithm Variations Tested

Combo #	*Sensor Combination*	*Background Subtraction*	*Training set*		*Magnitude Average*
			Size	*Alarm Criteria*	
1	ion, photo, CO, CO2	yes	140-pattern	0.82%	10-point
2	ion, photo, temp	yes	140-pattern	11%	25-point
3	ion, photo, temp	no	200-pattern	11%	25-point
4	ion, photo, CO	yes	54-pattern	N/A	25-point
5	ion, photo, CO, RH, CO2	no	308-pattern	11%	25-point
6	ion, photo, CO, RH, temp	no	308-pattern	11%	25-point
7	ion, CO, CO2	yes	140-pattern	11%	10-point
8	ion, photo, CO, CO2	yes	194-pattern	1.63%	10-point
9	ion, photo, CO, RH, CO2	no	200-pattern	11%	25-point
10	ion, photo, CO, RH, temp	no	200-pattern	11%	25-point

The various combinations were evaluated for both their classification performance and the speed of detection. The best performance results in faster detection of fires and slower detection of nonfires (EWFD either did not alarm for a nuisance source or the alarm was slower than that of the COTS instruments). Tables 31-40 show the results of combinations 1-10. The Tables give the classification results as well as descriptors to evaluate the overall speed. For example , a fire was recorded as faster than ion if the EWFD alarmed more than 30 seconds faster than the COTS ion. Similar performance means the results were within +/- 30 seconds of a COTS alarm. The best results were observed for the sensor combination used in real time and shown in Table 31. Using the same combination of sensors with an earlier alarm criterion as shown in Combination 1 and Table 32, the speed of fire detection increases, but the nuisance source rejection is reduced. The use of ION, Photo, and temperature with and without background subtraction (Combinations 2 and 3) reduces the overall classification performance and speed of detection (see Tables 33 and 34). Using only three sensors, ION, Photo, and CO and Test Series 1 and 2 for the training set, the fire detection is poor as shown in Table 35. Combinations 5 and 6 are the sensor combination used in Test Series 1 and 2 as Prototypes 1 and 2, respectively. When these combinations are trained with all the available data from Test Series 1 and 2 as well as the Laboratory

Table 30. Training Set Descriptions

Training Set	*Data Source*	*Number of Fires*	*Number of Nuisance Sources*	*Number of Backgrounds*
200-Pattern	Laboratory and SHADWELL 1999 Tests	95	45	60
140-Pattern	Laboratory and SHADWELL 1999 Tests	95	45	0
308-Pattern	Laboratory and SHADWELL 1999 Tests Test Series 1 & 2	129	65	114
194-Pattern	Laboratory and SHADWELL 1999 Tests Test Series 1 & 2	129	65	0
54-Pattern	Test Series 1 & 2	34	20	0

and *Shadwell* 1999 test data, the overall performance is poorer than the real time combination (see Tables 36, 37, and 31). The removal of the Photo sensor from the array reduces fire detection as shown in Table 38. When the data from Test Series 1 and 2 are included in the training set for the ION, Photo, CO and CO_2 sensors, the nuisance source rejection is reduced at Board A, and there is more variation between the individual prototypes (see Table 39). The results of Prototype 1 (as used in Test Series 1 and 2) are identical to the real time combination used in this Test Series, see Table 40. These results suggest that the relative humidity sensor (RH) contributed little to the array. It is surprising that the speed of the two combinations is identical given the differences in the Page 78 table 31/32 alarm criteria used. The results of Prototype 2 (as used in Test Series 1 and 2) provided poorer overall performance than the real time combination used in this Test Series as shown in Table 41. The results of this Test Series indicate that while Prototypes 1 and 2 were good choices, the optimized array and algorithm gave the best results.

8.4 Improved Real-Time Execution and Data Transfer

Modifications to the implementation of the real-time algorithm processing and data acquisition system were successful in providing a constant sampling interval of 2 seconds. This sampling rate can be maintained indefinitely. The system was also shown to be able to provide continuous real-time data to supervisory systems over the fiber optic LAN. The improvements and details addressing these two issues are addressed in Appendices A and B, respectively.

9.0 CONCLUSIONS

The results of this test series have demonstrated improved performance of the current PNN alarm algorithm compared to previous prototype designs as well as alternate sensor/PNN combinations evaluated in this work. The current alarm algorthim resulted in better overall performance than the commercial smoke detectors by providing both improved nuisance source immunity with generally equivalent to faster response times. Areas of improvement have been identified. In particular, it is believed that the prototypes can be made to respond faster to long smoldering fires.

Table 31. Real time Sensor Combination: Ion, Photo, CO, CO2 BS TS140 1.63% mag 10

Prototype	Total % Correct	Fires % Correct	Nuisance % Correct	Total # Correct	Fires # Correct	Nuisance # Correct	fires faster than ion	fires similar to ion	fires slower than ion	fires faster than photo	fires similar to photo	fires slower than photo	nonfires slower than ion	nonfires similar to ion	nonfires faster than ion	nonfires slower than photo	nonfires similar to photo	nonfires faster than photo
EWFD1	79.49	77.78	83.33	31	21	10	5	14	8	9	15	3	6	6	0	3	7	2
EWFD3	79.49	77.78	83.33	31	21	10	5	16	6	9	14	4	6	6	0	3	7	2
EWFD5	76.92	74.07	83.33	30	20	10	5	18	4	8	16	3	0	10	2	0	10	2
EWFD2	74.36	70.37	83.33	29	19	10	12	13	2	7	14	6	0	10	2	0	10	2
EWFD4	71.80	66.67	83.33	28	18	10	9	14	4	6	15	6	0	10	2	0	10	2
EWFD6	74.36	70.37	83.33	29	19	10	14	13	0	10	11	6	0	10	2	0	10	2
Avg	76.07	72.84	83.33	30	20	10	8	15	4	8	14	5	2	9	1	1	9	2

Table 32. Ion, Photo, CO, CO2 BS TS140 0.82% mag 10

Prototype	Total % Correct	Fires % Correct	Nuisance % Correct	Total # Correct	Fires # Correct	Nuisance # Correct	fires faster than ion	fires similar to ion	fires slower than ion	fires faster than photo	fires similar to photo	fires slower than photo	nonfires slower than ion	nonfires similar to ion	nonfires faster than ion	nonfires slower than photo	nonfires similar to photo	nonfires faster than photo
EWFD1	74.36	96.30	25.00	29	26	3	11	11	5	17	10	0	4	2	6	2	2	8
EWFD3	76.92	100.00	25.00	30	27	3	12	10	5	18	9	0	3	3	6	1	2	9
EWFD5	76.92	100.00	25.00	30	27	3	13	10	4	19	8	0	0	3	9	0	3	9
EWFD2	76.92	100.00	25.00	30	27	3	25	2	0	20	4	3	0	3	9	0	3	9
EWFD4	79.49	100.00	33.33	31	27	4	23	4	0	20	7	0	0	4	8	0	4	8
EWFD6	87.18	100.00	50.00	34	27	7	24	3	0	21	3	3	0	7	5	0	7	5
Avg	78.63	99.38	30.56	31	27	4	18	7	2	19	7	1	1	4	7	1	4	8

Table 33. Ion, Photo, Temp BS TS140 11% mag 25

Prototype	Total % Correct	Fires % Correct	Nuisance % Correct	Total # Correct	Fires # Correct	Nuisance # Correct	fires faster than ion	fires similar to ion	fires slower than ion	fires faster than photo	fires similar to photo	fires slower than photo	nonfires slower than ion	nonfires similar to ion	nonfires faster than ion	nonfires slower than photo	nonfires similar to photo	nonfires faster than photo
EWFD1	71.80	70.37	75.00	28	19	9	4	8	15	5	13	9	6	5	1	2	7	3
EWFD3	69.23	66.67	75.00	27	18	9	4	9	14	2	18	7	7	5	0	2	7	3
EWFD5	71.80	66.67	83.33	28	18	10	5	11	11	3	19	5	0	10	2	0	10	2
EWFD2	66.67	59.26	83.33	26	16	10	6	10	11	1	12	14	0	10	2	0	10	2
EWFD4	74.36	62.96	100.00	29	17	12	7	12	8	1	15	11	0	12	0	0	12	0
EWFD6	69.23	62.96	83.33	27	17	10	6	15	6	4	12	11	0	10	2	0	10	2
Avg	70.51	64.81	83.33	28	18	10	5	11	11	3	15	10	2	9	1	1	9	2

Table 34. Ion, Photo, Temp TS200 11% mag 25

Prototype	Total % Correct	Fires % Correct	Nuisance % Correct	Total # Correct	Fires # Correct	Nuisance # Correct	fires faster than ion	fires similar to ion	fires slower than ion	fires faster than photo	fires similar to photo	fires slower than photo	nonfires slower than ion	nonfires similar to ion	nonfires faster than ion	nonfires slower than photo	nonfires similar to photo	nonfires faster than photo
EWFD1	74.36	74.07	75.00	29	20	9	5	9	13	7	16	4	6	5	1	2	8	2
EWFD3	69.23	66.67	75.00	27	18	9	4	9	14	5	18	4	6	6	0	2	8	2
EWFD5	71.80	70.37	75.00	28	19	9	6	9	12	7	18	2	0	9	3	0	9	3
EWFD2	69.23	62.96	83.33	27	17	10	8	10	9	2	14	11	0	10	2	0	10	2
EWFD4	76.23	66.67	100.00	30	18	12	9	11	7	3	18	6	0	12	0	0	12	0
EWFD6	71.80	66.67	83.33	28	18	10	9	14	4	7	12	8	0	10	2	0	10	2
Avg	72.11	67.90	81.94	28	18	10	7	10	10	5	16	6	2	9	1	1	10	2

Table 35. Ion, Photo, CO TS54 mag 25

Prototype	Total % Correct	Fires % Correct	Nuisance % Correct	Total # Correct	Fires # Correct	Nuisance # Correct	fires faster than ion	fires similar to ion	fires slower than ion	fires faster than photo	fires similar to photo	fires slower than photo	nonfires slower than ion	nonfires similar to ion	nonfires faster than ion	nonfires slower than photo	nonfires similar to photo	nonfires faster than photo
EWFD1	71.80	66.67	83.33	28	18	10	4	12	11	3	18	6	6	6	0	3	7	2
EWFD3	64.10	55.56	83.33	25	15	10	4	11	12	5	13	9	7	5	0	3	7	2
EWFD5	71.80	66.67	83.33	28	18	10	5	14	8	5	19	3	0	10	2	0	10	2
EWFD2	53.85	40.74	83.33	21	11	10	3	13	11	3	13	11	0	10	2	0	10	2
EWFD4	64.10	48.15	100.00	25	13	12	7	14	6	2	15	10	0	12	0	0	12	0
EWFD6	61.54	51.85	83.33	24	14	10	5	15	7	4	13	10	0	10	2	0	10	2
Avg	64.53	54.94	86.11	25	15	10	5	13	9	4	15	8	2	9	1	1	9	2

Table 36. Ion, Photo, CO, RH, CO2 TS308 11% mag 25

Prototype	Total % Correct	Fires % Correct	Nuisance % Correct	Total # Correct	Fires # Correct	Nuisance # Correct	fires faster than ion	fires similar to ion	fires slower than ion	fires faster than photo	fires similar to photo	fires slower than photo	nonfires slower than ion	nonfires similar to ion	nonfires faster than ion	nonfires slower than photo	nonfires similar to photo	nonfires faster than photo
EWFD1	74.36	74.07	75.00	29	20	9	5	12	10	7	17	3	5	6	1	2	7	3
EWFD3	69.23	66.67	75.00	27	18	9	4	14	9	7	16	4	6	6	0	2	7	3
EWFD5	76.92	77.78	75.00	30	21	9	6	16	5	9	18	0	0	9	3	0	9	3
EWFD2	69.23	66.67	75.00	27	18	9	11	11	5	4	16	7	0	9	3	0	9	3
EWFD4	71.80	66.67	83.33	28	18	10	11	12	4	5	17	5	0	10	2	0	10	2
EWFD6	69.23	66.67	75.00	27	18	9	10	14	3	6	13	8	0	9	3	0	9	3
Avg	71.80	69.75	76.39	28	19	9	8	13	6	6	16	5	2	8	2	1	9	3

Table 37. Ion, Photo, CO, RH, Temp TS308 11% mag 25

Prototype	Total % Correct	Fires % Correct	Nuisance % Correct	Total # Correct	Fires # Correct	Nuisance # Correct	fires faster than ion	fires similar to ion	fires slower than ion	fires faster than photo	fires similar to photo	fires slower than photo	nonfires slower than ion	nonfires similar to ion	nonfires faster than ion	nonfires slower than photo	nonfires similar to photo	nonfires faster than photo
EWFD1	71.80	74.07	66.67	28	20	8	6	10	11	7	17	3	5	6	1	1	7	4
EWFD3	71.80	66.67	83.33	28	18	10	4	12	11	5	19	3	7	5	0	3	8	1
EWFD5	69.23	66.67	75.00	27	18	9	5	14	8	5	21	1	0	9	3	0	9	3
EWFD2	71.80	66.67	83.33	28	18	10	9	12	6	4	14	9	0	10	2	0	10	2
EWFD4	69.23	62.96	83.33	27	17	10	10	12	5	5	15	7	0	10	2	0	10	2
EWFD6	71.80	66.67	83.33	28	18	10	11	12	4	7	12	8	0	10	2	0	10	2
Avg	70.94	67.28	79.17	28	18	10	8	12	8	6	16	5	2	8	2	1	9	2

Table 38. Ion, CO, CO2 BS TS140 11% mag 10

Prototype	Total % Correct	Fires % Correct	Nuisance % Correct	Total # Correct	Fires # Correct	Nuisance # Correct	fires faster than ion	fires similar to ion	fires slower than ion	fires faster than photo	fires similar to photo	fires slower than photo	nonfires slower than ion	nonfires similar to ion	nonfires faster than ion	nonfires slower than photo	nonfires similar to photo	nonfires faster than photo
EWFD1	69.23	62.96	83.33	27	17	10	3	15	9	5	15	7	6	6	0	3	7	2
EWFD3	69.23	66.67	75.00	27	18	9	4	15	8	6	13	8	6	5	1	3	6	3
EWFD5	69.23	62.96	83.33	27	17	10	4	16	7	6	16	5	0	10	3	0	10	2
EWFD2	61.54	55.56	75.00	24	15	9	8	15	4	6	14	7	0	9	3	0	9	3
EWFD4	69.23	55.56	100.00	27	15	12	6	15	6	3	14	10	0	12	0	0	12	0
EWFD6	64.10	55.56	83.33	25	15	10	8	15	4	5	14	8	0	10	2	0	10	2
Avg	67.09	59.88	83.33	26	16	10	6	15	6	5	14	8	2	9	2	1	9	2

Table 39. Ion, Photo, CO, CO2 BS TS194 1.63% mag 10

Prototype	Total % Correct	Fires % Correct	Nuisance %Correct	Total # Correct	Fires # Correct	Nuisance # Correct	fires faster than ion	fires similar to ion	fires slower than ion	fires faster than photo	fires similar to photo	fires slower than photo	nonfires slower than ion	nonfires similar to ion	nonfires faster than ion	nonfires slower than photo	nonfires similar to photo	nonfires faster than photo
EWFD1	79.49	81.48	75.00	31	22	9	6	13	8	9	16	2	5	7	0	2	7	3
EWFD3	74.35	77.78	66.67	29	21	8	5	15	7	8	17	2	5	7	0	1	7	4
EWFD5	76.92	77.78	75.00	30	21	9	6	15	6	9	16	2	0	9	3	0	9	3
EWFD2	71.80	66.67	83.33	28	18	10	11	13	3	6	15	6	0	10	2	0	10	2
EWFD4	74.35	70.37	83.33	29	19	10	12	12	3	7	16	4	0	10	2	0	10	2
EWFD6	76.92	74.07	83.33	30	20	10	12	13	2	9	12	6	0	10	2	0	10	2
Avg	75.64	74.69	77.78	30	20	9	9	14	5	8	15	4	2	9	2	1	9	3

Table 40. Ion, Photo, CO, RH, CO2 TS200 11% mag 25

Prototype	Total % Correct	Fires % Correct	Nuisance %Correct	Total # Correct	Fires # Correct	Nuisance # Correct	fires faster than ion	fires similar to ion	fires slower than ion	fires faster than photo	fires similar to photo	fires slower than photo	nonfires slower than ion	nonfires similar to ion	nonfires faster than ion	nonfires slower than photo	nonfires similar to photo	nonfires faster than photo
EWFD1	79.49	77.78	83.33	31	21	10	5	14	8	9	15	3	6	6	0	3	7	2
EWFD3	79.49	77.78	83.33	31	21	10	5	16	6	9	14	4	6	6	0	3	7	2
EWFD5	76.92	74.07	83.33	30	20	10	5	18	4	8	16	3	0	10	2	0	10	2
EWFD2	74.36	70.37	83.33	29	19	10	12	13	2	7	14	6	0	10	2	0	10	2
EWFD4	71.80	66.67	83.33	28	18	10	9	14	4	6	15	6	0	10	2	0	10	2
EWFD6	74.36	70.37	83.33	29	19	10	14	13	0	10	11	6	0	10	2	0	10	2
Avg	76.07	72.84	83.33	30	20	10	8	15	4	8	14	5	2	9	1	1	9	2

Table 41. Ion, Photo, CO, RH, Temp TS200 11% mag 25

Prototype	Total % Correct	Fires % Correct	Nuisance % Correct	Total # Correct	Fires # Correct	Nuisance # Correct	fires faster than ion	fires similar to ion	fires slower than ion	fires faster than photo	fires similar to photo	fires slower than photo	nonfires slower than ion	nonfires similar to ion	nonfires faster than ion	nonfires slower than photo	nonfires similar to photo	nonfires faster than photo
EWFD1	71.80	74.07	66.67	28	20	8	5	12	10	8	14	5	4	8	0	1	7	4
EWFD3	69.23	70.37	66.67	27	19	8	4	14	9	7	18	2	6	6	0	1	7	4
EWFD5	71.80	74.07	66.67	28	20	8	5	14	8	9	17	1	0	8	4	0	8	4
EWFD2	71.80	66.67	83.33	28	18	10	10	12	5	4	16	7	0	10	2	0	10	2
EWFD4	71.80	66.67	83.33	28	18	10	10	13	4	6	14	7	0	10	2	0	10	2
EWFD6	74.36	70.37	83.33	29	19	10	11	14	2	8	12	7	0	10	2	0	10	2
Avg	71.80	70.37	75.00	28	19	9	8	13	6	7	15	5	2	9	2	0	9	3

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APPENDIX A– DATA ACQUISITION SYSTEM

A.1 General Description of the Data Acquisition Setup

The data acquisition system consisted of a desktop computer (dual Pentium 200Mhz, 128MB RAM, Windows NT 4.0) with data acquisition card (National Instruments AT-MIO-16F-5), and SCXI 1001 Chassis that housed three SXCI 1100 32-Channel amplifier modules. Attached to each module was a SCXI 1303 Terminal block. The three thermocouples used in this test series were connected to channels 0, 1, and 2 of the terminal block attached to the first amplifier module. Prototype detectors 1 through 5 were connected to channels 0 to 29 of the terminal block attached to the second amplifier. The last prototype and the residential ionization smoke detector were connected to channels 1 to 7 of the terminal block attached to the third amplifier module. Table A1 provides a summary of the channel setup.

Table A1. Channel Setup on Second Module of the Data Acquisition System.

Module	*Channel*	*Sensor*
1	0	Thermocouple
1	1	Thermocouple
1	2	Thermocouple
2	0	EWFD 1 System Sensor ionization smoke detector (type 7)
2	1	EWFD 1 System Sensor photoelectric smoke detector (type 1)
2	2	EWFD 1 carbon monoxide sensor (0-100ppm)
2	3	EWFD 1 relative humidity transmitter
2	4	EWFD 1 temperature transmitter
2	5	EWFD 1 carbon dioxide sensor (0-5000ppm)
2	6	EWFD 2 System Sensor ionization smoke detector (type 2)
2	7	EWFD 2 System Sensor photoelectric smoke detector (type 2)
2	8	EWFD 2 carbon monoxide sensor (0-100ppm)
2	9	EWFD 2 relative humidity transmitter
2	10	EWFD 2 temperature transmitter
2	11	EWFD 2 carbon dioxide sensor (0-5000ppm)
2	12	EWFD 3 System Sensor ionization smoke detector (type 5)
2	13	EWFD 3 System Sensor photoelectric smoke detector (type 4)
2	14	EWFD 3 carbon monoxide sensor (0-100ppm)
2	15	EWFD 3 relative humidity transmitter
2	16	EWFD 3 temperature transmitter
2	17	EWFD 3 carbon dioxide sensor (0-5000ppm)
2	18	EWFD 4 System Sensor ionization smoke detector (type 3)
2	19	EWFD 4 System Sensor photoelectric smoke detector (type 3)
2	20	EWFD 4 carbon monoxide sensor (0-100ppm)

Table A1. Channel Setup on Second Module of the Data Acquisition System. (continued)

Module	*Channel*	*Sensor*
2	21	EWFD 4 relative humidity transmitter
2	22	EWFD 4 temperature transmitter
2	23	EWFD 4 carbon dioxide sensor (0-5000ppm)
2	24	EWFD 5 System Sensor ionization smoke detector (type 11)
2	25	EWFD 5 System Sensor photoelectric smoke detector (type 9)
2	26	EWFD 5 carbon monoxide sensor (0-100ppm)
2	27	EWFD 5 relative humidity transmitter
2	28	EWFD 5 temperature transmitter
2	29	EWFD 5 carbon dioxide sensor (0-5000ppm)
3	1	EWFD 6 System Sensor ionization smoke detector (type 12)
3	2	EWFD 6 System Sensor photoelectric smoke detector (type 10)
3	3	EWFD 6 carbon monoxide sensor (0-100ppm)
3	4	EWFD 6 relative humidity transmitter
3	5	EWFD 6 temperature transmitter
3	6	EWFD 6 carbon dioxide sensor (0-5000ppm)
3	7	Residential Ionization Detector

Precision 249Ω resistors were bridged across the terminals of each sensor that provided 4-20mA output, so that the data acquisition could read the results in voltage. These sensors included the carbon monoxide sensors, carbon dioxide sensors, relative humidity transmitters, and temperature transmitters. Additionally, a voltage divider was constructed to reduce the output voltage of the residential ionization detectors to the range of the data acquisition system (-5V to +5V). The residential ionization detector's normal output range is ~3.5 to 7 V, which was reduced to ~1.75 to 3.5 V with the voltage dividers. The reduced output voltage is the value recorded in all of the test output files. The overall setup of the data acquisition system, including the sensors and fiber optic Ethernet connections is shown in Figure A1.

A.2 Description of the Software Inputs

Since the last test series the software has been revised a great deal, warranting a detailed explanation of the new inputs. Each major section of inputs is individually described below. Pictures of the data acquisition software are shown in Figures A2 and A3.

A.2.1 Device and Channel Information

The inputs in this section describe the hardware setup of the data acquisition system. The individual inputs are relatively straightforward, and are described in Table A2. Many of the values did not change between tests and were defaulted as indicated in the Table.

Table A2. Device and Channel Information Inputs.

Input	*Default Value*	*Description*
Device	1	Identifies the data acquisition card in the computer
Cold junction channel	ob0!sc1!md1!mtemp	Identifies the channel from which to read the cold junction compensation temperature (used in thermocouple measurements)
Offset channels	ob0!sc1!md1!calgnd ob0!sc1!md3!calgnd ob0!sc1!md2!calgnd	Identifies the channels from which to read the binary module amplifier offsets (used to reference data acquisition to ground). The thermocouple module must be first, followed by the "other channels" module, and finally the "Res Ion Channels" module.
TC channels	ob0!sc1!md1!0:2	Channels where thermocouples are connected
Other channels	ob0!sc1!md2!0:29	Channels where prototypes 1-5 are connected
Res Ion Channels	ob0!sc1!md3!1:7	Channels where prototype 6 and the residential ionization detector are connected.
TC input limits	0°C to 500°C	Used to set the voltage range from which thermocouple measurements will be made. (does not limit TC readings to this range)
TC type	K	Type of thermocouple used
CJC sensor	Thermistor	Type of sensor used to get the cold junction correction temperature
Voltage input limits	+5V to –5V	Voltage range of the data acquisition system

A.2.2 File Information

This block of inputs is used to define the path and filename for the output file. Inputs for the names of the three thermocouples are also provided. These names appear in a text header row in the output file that describes each individual data column.

A2.3 Data Acquisition Setup

The inputs provided in the "Data Acquisition Setup" section are used to control the timing aspects of the data collection and processing. Table A3 describes each of these inputs, as well as their respective default values.

Table A3. Device and Channel Information Inputs.

Input	*Default Value*	*Description*
Acquisition Delay Time	2 seconds	Sets the length of time that the system pauses between each data collection cycle.
Background Collection Time	1 minute	This sets the amount of time that the data acquisition system collects background data before calculating an 'average background reading' (ABR) for each of the sensors. Certain sensors use the ABR in the conversion from voltage to sensor reading.
Number of Samples to Average for Each Data Point	50	Each time the data acquisition system reads from a channel, it acquires this number of scans and averages them. This is done to reduce noise on the channel.
Scan Rate	1000/second	The actual speed at which data is read from each channel.

A.2.4 Sensor Voltage to Value Control

This input group represents one of the major software changes for this test series. The information is used to convert the raw voltages from the individual sensors to their respective engineering units. This was previously "hard-coded" in the software, making it difficult to change. The collection of inputs makes the conversion via the following relation:

*Sensor Reading = ((Voltage + Initial Offset) * Multiplier) + Final Offset*

In addition to the "Initial Offset", "Multiplier", and "Final Offset", three other inputs are provided. The "Sensor Name" and "units" are simply informational inputs. The last input is "Subtract Average Background Voltage from Initial Offset." This setting does exactly as its name implies, subtracting the average background voltage from the "Initial Offset" in the above equation. This setting was used in the conversion of the System Sensor ionization and photoelectric detector data.

Each group of inputs is representative of a single detector type and is referenced by an index number. In this way, each channel can be easily referenced its connected detector, and new detector types can be added simply by filling the inputs in the next highest unused index number.

A.2.5 Probabilistic Neural Network Setup

This input group controls the operation of the Probabilistic Neural Network (PNN) that is used to calculate the probability of alarm based on the sensor readings. As with the "Sensor Value to Voltage Control," each group of inputs is indexed to allow for multiple PNNs to be used. Table A4 describes the individual inputs.

Table A4. Probabilistic Neural Network Setup Inputs.

Input	*Description*
Alarm Probability	Sets the threshold probability level at which an alarm is caused.
Sigma	A characteristic variable of the PNN
PNN Type	If more than one PNN type has been coded, this input is used to set which particular PNN is used.
Number of tests in training set	Describes the number of tests that are included in the Tinfo and Training files.
Tinfo File Path	Gives the location of the file describing the test types contained in the Training file
Training File Path	Gives the location of the file containing the test data at various conditions
Data History Size	Sets the number of previous data points to store
Buffer Size	A PNN parameter.
Alarm History Size	Sets the number of previous alarm states to store

A.2.6 Sensor Array Information

These inputs control different aspects of the sensor arrays. The inputs are described in Table A5.

Table A5. Sensor Array Information Inputs.

Input	*Description*
Number of Sensor Arrays	Sets the number of sensor arrays attached to the system
PNN to use for Each Sensor Array	Each sensor array is assigned a PNN via the index number used to describe that PNN in the "Probabilistic Neural Network Setup"
Total Number of Sensors	Sets the total number of sensors in the system, not including thermocouples
Sensor Array Designation	A string of text, describing each sensor array. This information is added to the header row of the output file in the appropriate locations.

A.2.7 Channel Information

The inputs in this section are used to control the operation of each individual channel. The inputs are described in Table A6.

Table A6. Channel Information Inputs.

Input	*Description*
Index	This index is matched to the correct index from "Sensor Voltage to Value Control" for the device attached to the channel
PNN variable?	Indicates whether the value from the sensor should be passed to the PNN for processing
Sensor Array	Describes which sensor array of each channel (sensory arrays are numbered starting at zero)
PNN order	For each individual sensor array, this input describes the order in which PNN variables are passed to the PNN.

A.2.8 Other Inputs and Controls

There are a few other miscellaneous inputs and controls used by the software. These are described in Table A7.

Table A7. Miscellaneous Controls and Inputs.

Input	*Description*
TCP/IP Base Port Address	Sets the port at which a networked computer may attach to receive streaming data
Update Mode / Run Mode	Controls whether the program is set to update channel information only ("Update Mode") or collects and processes data ("Run Mode")
Event Tracking	Toggle switches that insert information into the output file at the time they are activated. Standard events can be indicated, such as "Ignition" and "Ventilation", as well as undefined events ("Event 1", "Event 4", etc.)
Alarm Lock	Controls the operation of the "alarm panel" indicators. In the "on" position, the alarm indicators will always stay on once an alarm condition has been reached. The 'off' position allows the alarm indicators to always show the true alarm state.

A.3 Limitations of the Data Acquisition System

There are a couple of limitations to the data acquisition setup. The software will not operate properly if these guidelines are not followed:

1) Only three amplifier modules may currently be used. This is due to a limitation in the measurement of binary amplifier offsets for each module. The software has been set up to read only three of these values. When these channels are specified in the "offset channels" input, the thermocouple module must be listed first, followed by the "Res Ion" module, and finally the "other sensors" module. These limitations restrict the system to 32 thermocouples and 64 other devices.

2) The data acquisition card is limited to 200,000 total scans per second. Specifying a scan rate per channel that exceeds this limit for the number of channels being scanned will degrade data acquisition performance.

The processing sequence of the data acquisition was as follows:

1) Acquire background data for the length of time indicated by the user (60 seconds was used in these tests). Average values of each of the sensor readings are taken from this background data. During this period, the values read from the System Sensor detectors are voltages. The average voltage from the System Sensor detectors is then used to calculate the ΔMIC and %/ft outputs for the ionization and photoelectric detectors, respectively. The remainder of the averages from the other sensors is not used.

2) After the background period has passed, the calculations involved with the probabilistic neural network begin to be executed.

3) Once 25 post-background data points have been taken, alarm probability values are calculated.

4) The data collection continues until stopped by the user.

A.4 Output from the Data Acquisition System

The output file generated by the data acquisition system was a comma-delimited text file. The test time, individual sensor readings, and probability and alarm conditions for each prototype detector were included in the file. The first row contains the header information for each column, and each row thereafter is the data taken at the next time. Table A3 gives a complete description of the output files generated in this test series.

Table A8 – Format of the Output File

Column	*Description*	*Prototype*	*Sensor Range*	*Input Range to Data Acquisition System*	*Units of Values in Output File*
1	Military time	-	-	-	HH:MM:SS
2	Elapsed time	-	-	-	Sec
3	Alarm condition	1	-	-	1 = ON, 0 = OFF
4	Probability of alarm	1	-	-	Dimensionless (0-1)
5	Alarm condition	2	-	-	1 = ON, 0 = OFF
6	Probability of alarm	2	-	-	Dimensionless (0-1)
7	Alarm condition	3	-	-	1 = ON, 0 = OFF
8	Probability of alarm	3	-	-	Dimensionless (0-1)
9	Alarm condition	4	-	-	1 = ON, 0 = OFF
10	Probability of alarm	4	-	-	Dimensionless (0-1)
11	Alarm condition	5	-	-	1 = ON, 0 = OFF
12	Probability of alarm	5	-	-	Dimensionless (0-1)
13	Alarm condition	6	-	-	1 = ON, 0 = OFF
14	Probability of alarm	6	-	-	Dimensionless (0-1)

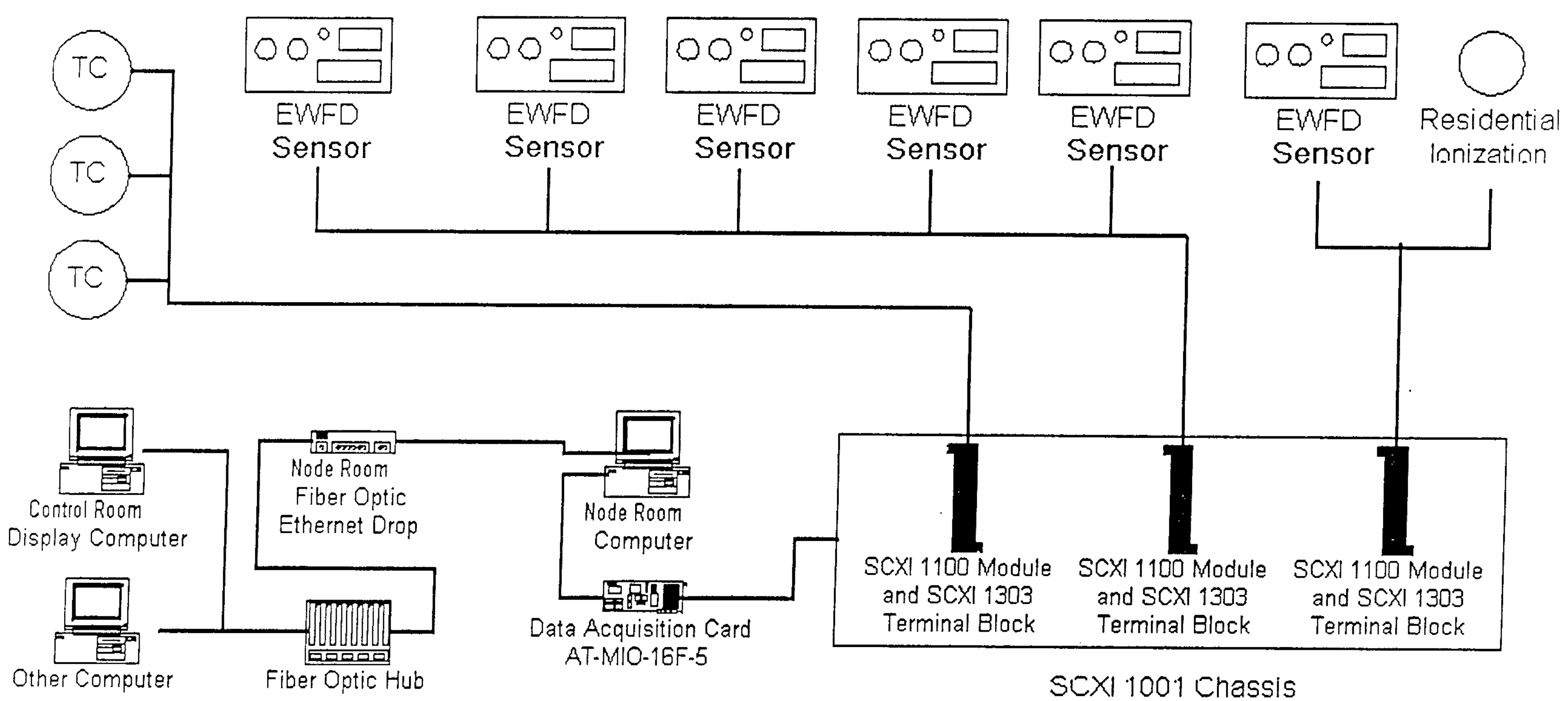
Table A8 – Format of the Output File (continued)

Column	*Description*	*Prototype*	*Sensor Range*	*Input Range to Data Acquisition System*	*Units of Values in Output File*
15	System Sensor ion detector	1	N/A (See Table 6)	0-5V	ΔMIC
16	System Sensor photo detector	1	N/A (See Table 6)	0-5V	%/ft
17	Carbon monoxide	1	0-100ppm	1-5V	ppm
18	Relative humidity	1	0-100%	1-5V	%
19	RTD Temperature	1	-20 to 75°C	1-5V	°C
20	Carbon dioxide	1	0-5000ppm	1-5V	ppm
21	System Sensor ion detector	2	N/A (See Table 6)	0-5V	ΔMIC
22	System Sensor photo detector	2	N/A (See Table 6)	0-5V	%/ft
23	Carbon monoxide	2	0-100ppm	1-5V	ppm
24	Relative humidity	2	0-100%	1-5V	%
25	RTD Temperature	2	-20 to 75°C	1-5V	°C
26	Carbon dioxide	2	0-5000ppm	1-5V	ppm
27	System Sensor ion detector	3	N/A (See Table 6)	0-5V	ΔMIC
28	System Sensor photo detector	3	N/A (See Table 6)	0-5V	%/ft
29	Carbon monoxide	3	0-100ppm	1-5V	ppm
30	Relative humidity	3	0-100%	1-5V	%
31	RTD Temperature	3	-20 to 75°C	1-5V	°C
32	Carbon dioxide	3	0-5000ppm	1-5V	ppm
33	System Sensor ion detector	4	N/A (See Table 6)	0-5V	ΔMIC
34	System Sensor photo detector	4	N/A (See Table 6)	0-5V	%/ft
35	Carbon monoxide	4	0-100ppm	1-5V	ppm
36	Relative humidity	4	0-100%	1-5V	%
37	RTD Temperature	4	-20 to 75°C	1-5V	°C

Table A8 – Format of the Output File (continued)

Column	*Description*	*Prototype*	*Sensor Range*	*Input Range to Data Acquisition System*	*Units of Values in Output File*
38	Carbon dioxide	4	0-5000ppm	1-5V	ppm
39	System Sensor ion detector	5	N/A (See Table 6)	0-5V	ΔMIC
40	System Sensor photo detector	5	N/A (See Table 6)	0-5V	%/ft
41	Carbon monoxide	5	0-100ppm	1-5V	ppm
42	Relative humidity	5	0-100%	1-5V	%
43	RTD Temperature	5	-20 to 75°C	1-5V	°C
44	Carbon dioxide	5	0-5000ppm	1-5V	ppm
45	System Sensor ion detector	6	N/A (See Table 6)	0-5V	ΔMIC
46	System Sensor photo detector	6	N/A (See Table 6)	0-5V	%/ft
47	Carbon monoxide	6	0-100ppm	1-5V	ppm
48	Relative humidity	6	0-100%	1-5V	%
49	RTD Temperature	6	-20 to 75°C	1-5V	°C
50	Carbon dioxide	6	0-5000ppm	1-5V	ppm
51	Residential ion detector	-	typically 3.5 - 7V	0-5V	Volts (1/2 of actual output)
52	Thermocouple at Source Location	-	-200 to 1350°C	mV	°C
53	Thermocouple at A location	-	-200 to 1350°C	mV	°C
54	Thermocouple at B location	-	-200 to 1350°C	mV	°C
55	Event (#)	-	-	-	None (numerical indication of an event)
56	Event (description)	-	-	-	None (text description of an event)

Fig. A1 - Data Acquisition Setup



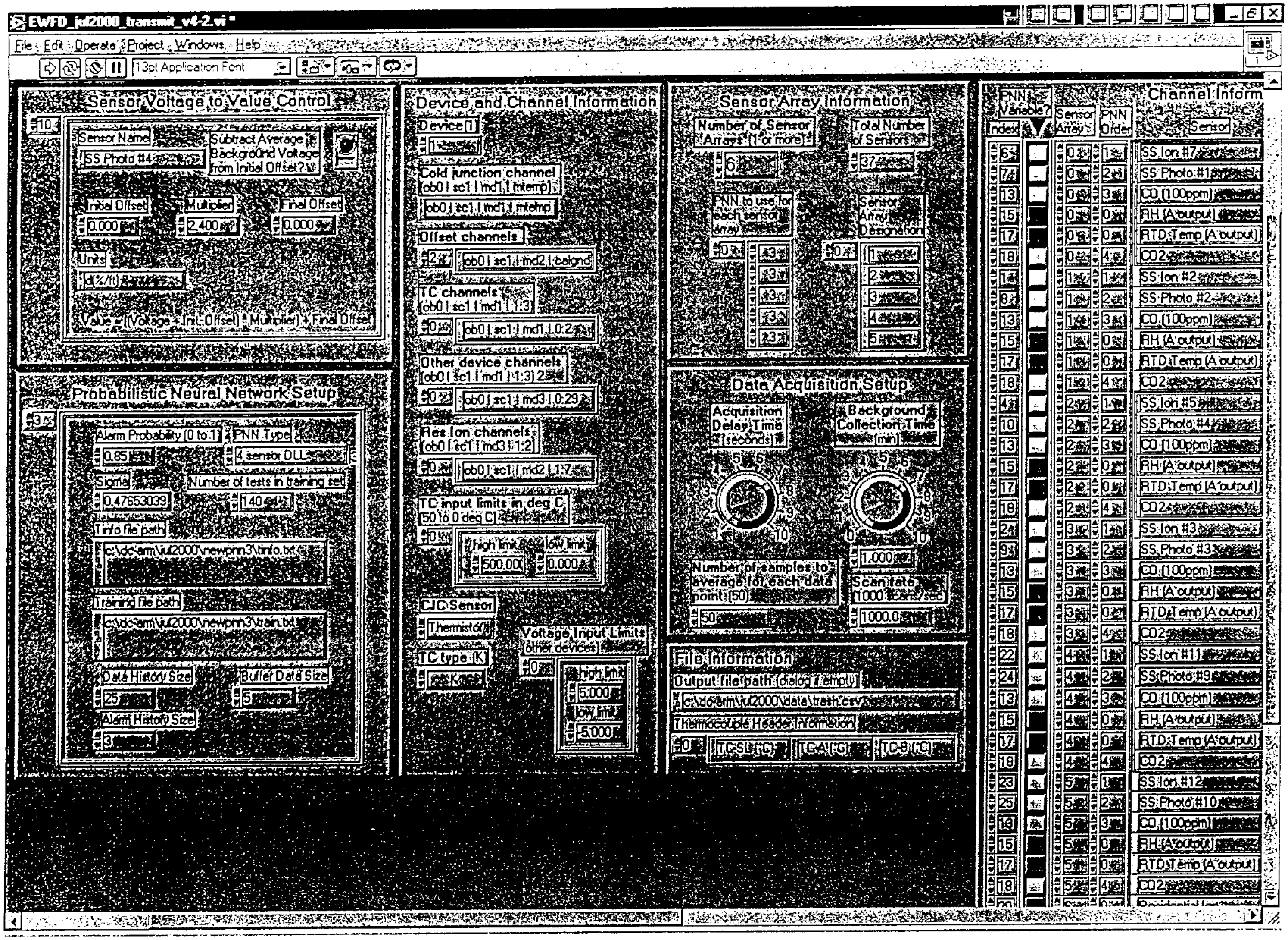


Figure A2. Picture of the Data Acquisition Software Screen

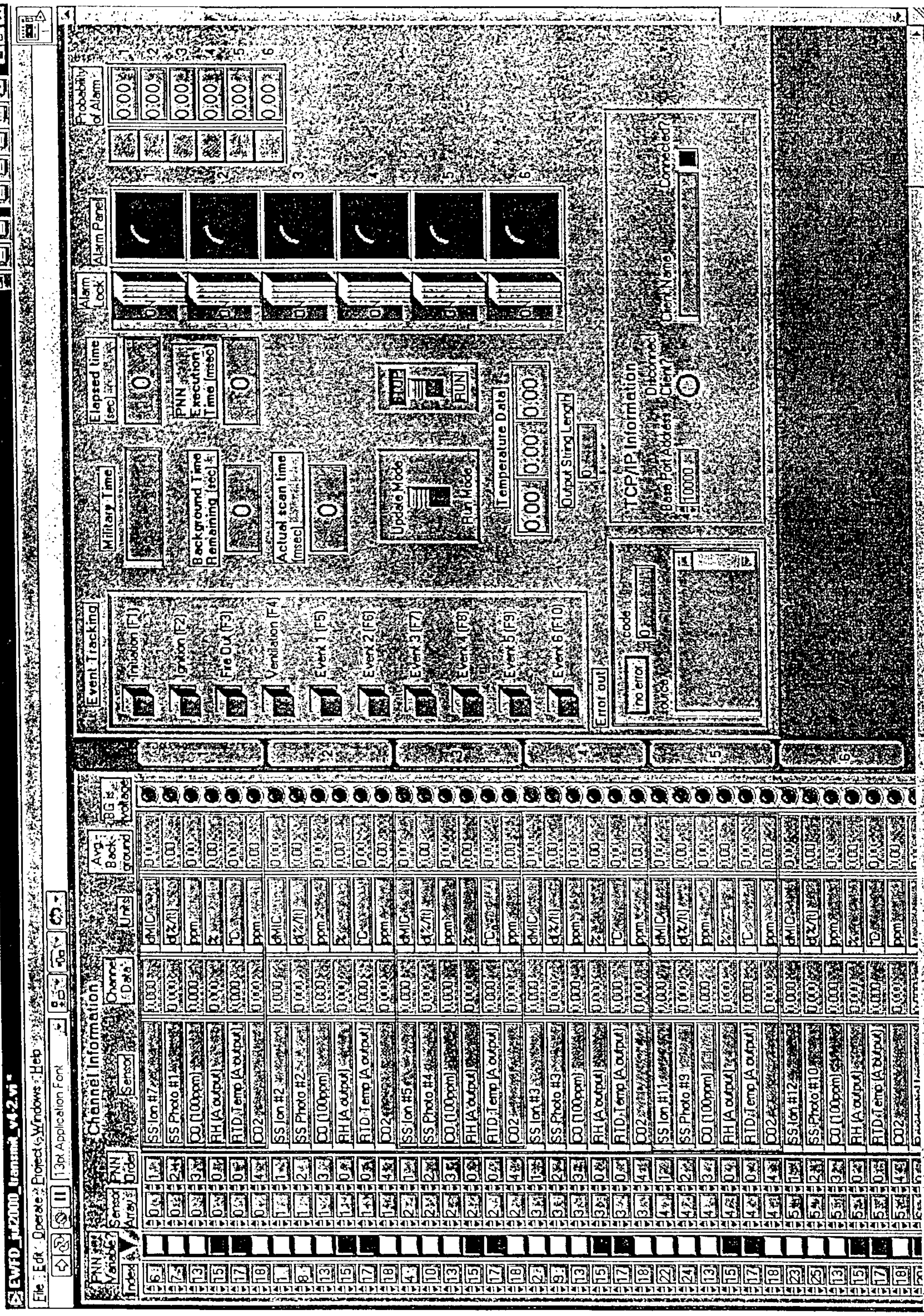


Figure A3. Picture of the Data Acquisition Software Screen

APPENDIX B – OUTPUT DATA FORMAT

Early Warning Fire Detector (EWFD) Data Output Format

In order for the supervisory groups to access the data, it was made accessible through direct TCP/IP transfer. At each timestep, the data was broadcast to a designated TCP/IP port address on the node room computer (IP 89.0.0.66, Port 10000) as a 400 character string, consisting of time, alarm, probability, and sensor data. Commas separated the data, and an end of line character was placed at the end of the string. The actual structure of the string is described in Table B1. A limitation of this method is that only the current data from the data acquisition system is available to the supervisory control system groups. Table B2 provides a more detailed description of each data type, along with an example.

Table B1 – Structure of the TCP/IP Output String.

Data Field	*Field Width*	*Separating Character Width*	*Total Width*
Military time	8	1	9
Test time	6	1	7
Alarm status 1	7	1	8
Probability 1	7	1	8
Alarm status 2	7	1	8
Probability 2	7	1	8
Alarm status 3	7	1	8
Probability 3	7	1	8
Alarm status 4	7	1	8
Probability 4	7	1	8
Alarm status 5	7	1	8
Probability 5	7	1	8
Alarm status 6	7	1	8
Probability 6	7	1	8
System Sensor ion 1	7	1	8
System Sensor photo 1	7	1	8
Carbon monoxide 1	7	1	8
Relative humidity 1	7	1	8
RTD temperature1	7	1	8
Carbon dioxide1	7	1	8
System Sensor ion 2	7	1	8
System Sensor photo 2	7	1	8
Carbon monoxide 2	7	1	8
Relative humidity 2	7	1	8

Table B1 – Structure of the TCP/IP Output String (continued)

Data Field	*Field Width*	*Separating Character Width*	*Total Width*
RTD temperature 2	7	1	8
Carbon dioxide 2	7	1	8
System Sensor ion 3	7	1	8
System Sensor photo 3	7	1	8
Carbon monoxide 3	7	1	8
Relative humidity 3	7	1	8
RTD temperature 3	7	1	8
Carbon dioxide 3	7	1	8
System Sensor ion 3	7	1	8
System Sensor photo 4	7	1	8
Carbon monoxide 4	7	1	8
Relative humidity 4	7	1	8
RTD temperature 4	7	1	8
Carbon dioxide 4	7	1	8
System Sensor ion 5	7	1	8
System Sensor photo 5	7	1	8
Carbon monoxide 5	7	1	8
Relative humidity 5	7	1	8
RTD temperature 5	7	1	8
Carbon dioxide 5	7	1	8
System Sensor ion 6	7	1	8
System Sensor photo 6	7	1	8
Carbon monoxide 6	7	1	8
Relative humidity 6	7	1	8
RTD temperature 6	7	1	8
Carbon dioxide 6	7	0	8
End of line character	1	0	1
		Total	**400**

Table B2 – Description of Each Field.

Data Field	*Units*	*Example*	*Description*
Military time	HH:MM:SS	14:23:45	Military time in hours, minutes, and seconds
Test time	seconds	345	Elapsed time into experiment (including background collection)
Alarm status	None	1	-1=Background collection, 1=Alarm, 0=No Alarm
Probability	None	0.65	Probability of alarm (range is from 0 to 1, -1 indicates background collection)
System Sensor ion	ΔMIC	10.21	Output from the ionization detector, negative values are possible.
System Sensor photo	%/ft	5.21	Output from the photoelectric detector, negative values are possible
Carbon monoxide	ppm	53.1	Carbon monoxide concentration, negative values are possible (0-100ppm range)
Relative humidity	%	65.8	Relative humidity (0-100% range)
RTD temperature	°C	31.21	Temperature as measured from the RTD unit on the prototype (-20 to 75°C range)
Carbon dioxide	ppm	1380.4	Carbon dioxide concentration (0-5000ppm range)